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RELATIONSHIPS BETWEEN GRAIN YIELD AND GROWTH RATES OF PLANT PARTS AS INFLUENCED BY MALE STERILE CYTOPLASMS, PLANT DENSITIES, and HYBRIDS IN CORN (ZEA MAYS L.)

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Relationships between grain yield and growth rates of plant parts as influenced by male sterile cytoplasms, plant densities, and hybrids in corn (*Zea mays* L.)

by

Anosike Madukiro Enyinnaya

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INTRODUCTION

After the 1970 incidence of blight on corn hybrids with the Texas male sterile cytoplasm (Tms), other and newer types of cytoplasmic male sterility (Cms and Sms) have been used in corn production. More physiological information needs to be obtained on these new male sterile hybrids.

Cytoplasmic male sterile systems in corn have been generally classified into three groups designated as T, C, and S groups, corresponding with Tms, Cms, and Sms, respectively. Classifications were based on their responses to restorer genes in inbred lines and the degree of pollen sterility (Briggle, 1956; Beckett, 1971; Gracen and Grogan, 1974).

Among the three groups, the Tms has been foremost in use. It established its lead early in the history of cytoplasmic male sterility when it proved to be more stable than Rhodes (1931) cytoplasm, another male sterile cytoplasm at the time (Rogers and Edwardson, 1952). From then until 1970, much of all the work on male sterility has been done on Tms, almost in exclusion of the other groups.

It has been reported that the most important economic application from the discovery and use of cytoplasmic male sterility in corn has been its use in commercial production of hybrid seed. It has been used extensively because it eliminated costly and laborious detasseling. Besides, more recently, there have also been strong indications that male

sterility applications may be economically important in some other aspects including yields (Duvick, 1958; Chinwuba et al., 1961; Sanford et al., 1965; Schwanke, 1965).

In 1970, the destructive southern corn leaf disease, Helminthosporium maydis occurred in corn with Tms and became a great setback to its use (Hooker et al., 1970).

Since this incidence of H. maydis on Tms, there appears to be much scepticism in the use of male sterile components--Tms or others outside the T group, notably C and S groups. There seems to be, not only the fear of breakdown or susceptibility to some disease like H. maydis, but also fear of lack of adequate information and evidence of high performance and sustained high yields if C and S cytoplasmic male sterile materials are used.

Beckett (1971) considers Cms and Sms as promising substitutues for Tms, since they are more resistant to H. maydis than Tms. Smith et al. (1971) tested members of C and S groups and found them resistant to H. maydis.

Gracen and Grogan (1974) evaluated the different cytoplasms of 38 different male sterile cytoplasmic versions of 29 inbred lines as to their suitability for hybrid production, based on completeness and stability of sterility and resistance to H. maydis. They concluded from their study that hybrid corn production would be feasible and practical using other male sterile cytoplasm outside the T group.

Apart from the above recommendation, there appears to be

very scanty and inadequate information on the performance and yield potentials of the other groups of cytoplasmic male sterility in corn. Such information needs to be obtained.

Various studies have been reported in the literature which virtually establish the fact that cytoplasmic male sterile corn hybrids give greater grain yields under above-optimum plant densities than their fertile counterparts (Duvick, 1958; Chinwuba et al., 1961; Sanford et al., 1965; Schwanke, 1965).

While there is a high degree of agreement on such yield superiority of cytoplasmic male sterile corn hybrid, there is still no such consensus on the reason(s) for their superior performance. The physiological and or morphological factors directly associated with the grain yields of cytoplasmic male sterile corn, under high plant densities, appear to continue to remain a matter of speculation.

The purpose of this study is to evaluate the performance of some hybrids carrying the Cms or Sms cytoplasmic male sterility under high plant density, particularly with regard to grain and silage yields; also to find an explanation for the often greater yields of male sterile corn compared to their fertile counterparts under above-optimum plant densities. Both of these objectives may affect any present and future uses of cytoplasmic male sterility.

The objectives of the experiment may therefore be stated as follows:

1. To determine the grain and forage yields of some hybrids carrying the Cms or Sms cytoplasmic male sterility systems under different plant densities.
2. To determine what relationships exist between growth rates of various plant parts that would help explain the greater yields of male sterile corn compared to the fertile counterpart under supraoptimum plant densities; in other words, to determine why male sterile corn plants outyield their fertile counterparts at above-normal plant population.

LITERATURE REVIEW

A number of important factors have been responsible for the increases in corn yields obtained in the United States, particularly in the Corn Belt over the past several years. Increased plant densities, improved hybrids, and improved soil fertility practices have been major factors.

Population Density Effect

Agricultural yield with respect to grain has been shown to be a function of plants/area x heads/plant x seeds/head and weight/seed (Mitchell, 1970). In these recent years with the popularity of single-ear hybrids, the corn farmer makes his yield by planting appropriate high plant density, providing soil fertility and weather conditions are adequate. Frequently, however, hybrids that have been considered high yielding at lower plant densities and high fertility levels fail to give increased yield at higher plant densities. Such hybrids often have high percentage of barren plants which may reduce yields.

Several studies have been done investigating the effects of increased plant density on several plant and ear characteristics as well as yields. Colville et al. (1964) reported that the recommended rates of planting (which they claimed was supported by seven other authors) ranged from 29,652 to 59,304 plants/hectare (12,000 to 24,000/A) in humid areas and

14,826-29,652 plants/hectare for nonirrigated semiarid regions. The increased rates resulted in yield increases. More recent results of increased yields with increasing population have been reported as typified by the work of Hunter et al. (1970) and Moll and Kamprath (1977). These studies have shown positive responses to population increases, the increased barrenness among plants notwithstanding. It should and has been noted that different genotypes and environments affect the response to increased population. Some other factors, therefore, are involved in the relationship between density and yield. It has been shown that increases in plant density, while affecting the corn yield, also affects other plant characters. Plant height, ear height, number of ears per plant, ear size and weight, and the silking/pollen shedding interval are some of the plant characters affected by plant density (Wolf and Howard, 1957; Colville and McGill, 1962; Ortiz-Cereceras, 1967; El-Lakany, 1970; El-Lakany and Russell, 1971).

There is a general trend of increased plant and ear height as plant density increases. Zuber and Grogan (1956), Zuber et al. (1960), Colville and McGill (1962), and Rutger and Crowder (1967) all agree on this finding.

Zuber and Grogan (1956) also reported that the number of ears per plant decreased as plant density increased. Their finding was confirmed by other workers: Wolf and Howard (1957), Dungan et al. (1958), Zuber et al. (1960), Norden

(1961), and Warren (1963). Ear length and weight also decreased as plant density increased.

Seed size was reported to be decreased and differed significantly when plant population changed from 29,652 to 59,304 plants/hectare (Ortiz-Cereceras, 1967).

Studies by Baracco (1961), Woolley et al. (1962), and Rossman and Cook (1966) revealed that increased plant densities affected date of silking. The number of days between pollen shed and silk emergence was increased by 1-5 days as a result of a delay in silking due to increased plant density. Shubeck and Caldwell (1955) reported that an increase in plant density from 8,787 to 48,184 plants/hectare resulted in five days delay in 50% silk emergence. Woolley et al. (1962) noted a significant 1.2 days increase in the interval between pollen shed and silking in a favorable year, and a 4.4 days increase in the interval in an unfavorable year as the population was increased from 39,536 to 59,304 plants/hectare. The percentage of barren plants correspondingly increased 3.6% and 15.4%.

Hybrid or Genotype Effect

Although studies have, in general, shown a trend of yield responses to increased population levels, it must be kept in mind that these studies have used hybrids of different genetic constitutions, which have responded to environments and levels of plant densities. The part played by genetic constitution

of a hybrid, through the inherent yield potential and tolerance to high density and other types of stresses, is of primary importance in determining the response to plant density.

Studies have shown the importance of the nature of the hybrid. Lutz et al. (1971), in their study to investigate the relationships among hybrids, row spacing and population, and yield of corn, found that although population, row spacing and hybrid affected yield, the hybrid genotype appeared to have a greater effect on yield than did plant density. Yield from a late hybrid was greater than that from early or medium hybrids regardless of population.

Schwanke (1965) categorized 26 genotypes into population tolerant and population intolerant classes based on yield at high population densities. He found that reduced stalk barrenness and larger ear weights were associated with the tolerant genotypes.

Bauman (1959), Zuber et al. (1960), Josephson (1961), and Hinkle and Garrett (1961), all showed that southern prolific genotypes, unlike the single-ear hybrids, exhibited little if any whole plant barrenness under high population, except in a case where extreme population density was used. The authors reported that population pressure in prolific hybrids or genotypes was expressed as adjustments in the number of ears per stalk, with only slight ear weight changes. In the single or semiprolific genotypes, barrenness usually

results. Bauman (1959) found that 162 prolific hybrids averaged 1.10 ears per plant at 54,362 plants/hectare, whereas 173 single-ear hybrids produced an average of only 0.90 ears per plant at 44,478 plants/hectare.

Collins et al. (1965) compared 36 single-cross Corn Belt hybrids involving one-eared and two-eared inbred lines at four planting densities. He found the two-ear type to yield greater than the single-ear types as a result of their capacity to adjust to environmental fluctuations including plant density by changing the number of ears per plant produced.

Rossman (1955) had earlier reported that double-cross hybrids exhibited diverse responses to plant densities and that genotypes productive at low population densities seemed to be productive at high population also. The marked differential responses of single-crosses and inbreds to population levels with respect to stalk barrenness, on the other hand, were noted by Sass and Loeffel (1959).

Fertility Practices and Other Environmental Effects

Numerous studies have been done on the response of corn to various fertilizer treatments; Swanson and Tyner (1965), Voss and Pesek (1967), Colyer and Kroth (1968, 1970), Ketcheson and Beauchamp (1978), and Nicholaides et al. (1979) are typical. In all of these studies, the need for the adequate use of fertilizers for the realization of a high corn yield

has been clearly shown. Some of the studies have tried to establish the economic maximum rates of use of various nutrients (Colyer and Kroth, 1968). The studies have also generally brought out other factors such as plant density and soil moisture regimes that may interact or affect use of fertilizers. Any crop may vary in its response to applied nutrient, depending on plant density, location, season and weather characteristics (Voss and Pesek, 1967; Colyer and Kroth, 1968, 1970). Yield may tend to increase with increased population, but normally this also means increased need for nutrition (Colyer and Kroth, 1968).

Moisture has been shown to be of particular importance in crop growth and fertilizer use (Denmead and Shaw, 1960; Claassen and Shaw, 1970; Vincent and Woolley, 1972). Plant moisture stress is accentuated under increased population. However, some genotypes may tolerate low moisture conditions through efficient use of moisture. Bruce et al. (1966, 1969) considered male sterile corn more efficient than the fertile type in use of moisture. Vincent (1968) found that under moisture and plant density pressure, male sterile genotypes yielded 3.3 quintals/hectare greater than the fertiles, but it was not statistically significant.

Date of planting may also affect yields of corn under adequate fertility programs. Early planting was shown to be superior in yield to late planting (Boone et al., 1966; Pendleton and Egli, 1969; Cardwell, 1967). High population

tolerant hybrids were reported by Cardwell (1967) to be less affected by planting date. Barrenness and nubbin ear production were the factors resulting in reduced yield of late planting.

Reasons for Increased Barrenness Under High Plant Density

Reductions in yield due to increased plant density have been attributed largely to the increased number of barren plants. Efforts have been made to understand and explain the process that leads to the barrenness, i.e., physiological or morphological explanations.

A few suggestions have been given to explain why corn plants go barren under high population. Such reasons include delays in silking and/or ear primodia growth and inter- and intraplant competition involving carbohydrate and nitrogen metabolisms.

Delayed silk or ear primodia

Schwanke (1965) and Cardwell (1967) found barrenness associated with population intolerant genotypes to be directly related to a greater number of days to reach 75% silked plants. Silking in population tolerant hybrids was less affected by plant density (Cardwell, 1967). Sass and Loeffel (1959) concluded from their study that barrenness associated with plant densities was the result of silks failing to emerge during the pollination period, rather than as a result of

floral organs failing to develop. They also suggested that competitive pressure does not produce marked retardation of ear or silk elongation until approximately 68-74 days after planting, at which time population greatly retards growth of these two parts. This appears to coincide with Collins' (1963) finding that the period 3 weeks before anthesis is a critical period. Moss and Stinson (1961) showed barrenness associated with shading from high population to be specific on the silking process and not on ear differentiation. Silks generally emerged, but the silk growth was usually retarded beyond the shedding of pollen in intolerant varieties. Woolley et al. (1962) found barrenness and longer silking interval to be closely associated, especially under unfavorable moisture supply or high population.

Inter- and intraplant competition

Cardwell (1967) believed that under competitive condition of high population, carbohydrate metabolism was severely affected. He found that barrenness increased with an associated decrease in stalk sugar level as planting date was delayed (stalk sugar is known to contribute to grain yield in corn (Daynard et al., 1969)). Therefore, he concluded that the level of sugar prior to pollination could explain the barrenness due to planting date. Williams et al. (1968) suggested that stalk sugar just prior to pollination may have a predictive value relative to fruit set, since at this stage

there was a declining sugar percentage with increasing plant density. They stated that the absolute amount of sugar present in a plant is a function of the plant weight and concentration of sugar, and they found the absolute amount of sugar at high plant density considerably less. Williams et al. (1968) then concluded that such small amounts of sugars and other metabolites to be the probable cause of barrenness at high plant density.

Although stalk sugar concentrations through the critical periods have been shown to vary in inbreds, Cardwell (1967), Williams et al. (1968), Van Reen and Singleton (1952) have observed that not all the differences in sugar level can be explained by grain yield. Moss and Stinson (1961) and Sowell et al. (1961) considered stalk sugar a small factor in distinguishing between population tolerant and population intolerant hybrids, or a factor influencing barrenness. Knipmeyer et al. (1962) agreed that carbohydrate metabolism was not a limiting factor.

Zieserl et al. (1963) and Knipmeyer et al. (1962) considered nitrogen metabolism more severely affected than carbohydrate metabolism under competitive conditions and shading. Nitrate reductase, a substrate induced light-dependent enzyme, was very adversely affected by the shading of high plant density and they argued that this led to reduction of nitrate reductase activity, protein content and yield. Zieserl et al. (1963) and Knipmeyer et al. (1962) found that

population tolerant hybrid Hy2 x Oh7 had higher nitrate reductase level than population intolerant Wf9 x C103; furthermore, a grouping of some hybrids according to nitrate reductase level agreed with their agronomic yield performance. However, Cardwell (1967) found that C103 x Hy, a population intolerant hybrid, had greater nitrate reductase activity than that of more tolerant hybrids. He concluded that having high nitrate reductase activity does not necessarily make a hybrid population tolerant.

Male Sterility

An additional factor shown to affect corn yield under high population density and through its effects on the degree of barrenness is cytoplasmic male sterility.

The earliest observations on the effect of male sterile plants were reported by Schweitzher (1889) and Watson (1893). Male sterile corn plants were represented by detasseled corn in these studies. Watson (1893) reported as much as 50.2% increase in yield as a result of detasseling. The initial reports were followed by a number of studies on the effect of detasseling, and included those of Leonard and Kiesselbach (1932), Isidoro (1934), Dungan and Woodworth (1939), and Kiesselbach (1945). Most of the studies showed increased yield responses to detasseling. Some yield decreases were also recorded primarily resulting from damages or removal of leaves during detasseling. All cases of leaf damage and

removal during detasseling reduced yields.

Grogan (1956) studied the physiological factors affecting the detasseling yield response of corn as affected by climate, soil and competitive condition. He concluded that under stress conditions, such as drought, low soil fertility and/or above-normal plant population density, yield increases associated with detasseling were due to the elimination of competition for nutrients between the ear and the tassel. He predicted that similar results could be explected from cytoplasmic male sterility.

Cytoplasmic male sterility was first discovered by Rhodes in 1931 in an open-pollinated Peruvian corn. Then followed the discovery of Texas male sterile cytoplasm by Rogers in 1944, as reported by Rogers and Edwardson (1952). The more stable Tms quickly replaced the less stable Rhodes cytoplasm source (Rogers and Edwardson, 1952).

Although early work with Tms gave inconsistent yield increases, results across several genotypes and environments showed significant increases for several single and double crosses under drought conditions. The work of Duvick (1958), Chinwuba et al. (1961), and Schwanke (1965) substantiated Grogan's prediction that cytoplasmic male sterility would result in increased yield under stressful conditions as did detasseling. Duvick (1958) concluded from his work that sterile genotypes tended to yield more than their normal counterparts as plant density increased. He considered plant

barrenness as the plant attribute most closely related to the yields. Chinwuba et al. (1961) observed a 41.2% yield advantage by the male sterile genotype over the fertile genotype at 66,717 plants/hectare, and only 17.5% yield advantage at 32,617 plants/hectare. Schwanke (1965) obtained similar results to those of Chinwuba et al. (1961). The yield advantage of the genotypes in his study were primarily due to reduced barrenness. Both detasseling and cytoplasmic male sterility appeared to reduce the harmful effect of high plant densities, and thereby raising the optimum production by a genotype. Meyer (1970) obtained similar barrenness reducing effect from cytoplasmic male sterile hybrids.

Many researchers reported results that were in agreement with Grogan's (1956 prediction concerning the effect cytoplasmic male sterility might have on yield. Nevertheless, not all researchers substantiated the prediction. Everett (1960), Johnston and Snyder (1962), and Josephson and Kincer (1962) all concluded from their works that there were no consistent cytoplasmic effects on either pollen sterile or restored hybrids; but rather that genotypes varied in response to plant density for agronomic characters such as yield. Noble and Russell (1963) and Marquez-Sanchez (1964) found a reduction in yield of 1.1 and 4.3%, respectively, at 39,536 plants/hectare for restored hybrids of Tms when compared to the same genotypes in normal cytoplasm.

Duvick (1965) tested 67 three-way crosses of restored

hybrids in both normal and Tms. He found the average yields of the sterile hybrids to be the same as their normal cytoplasm counterparts, but the restored-normal hybrids yielded on the average 2% more than the restored steriles. This finding led Duvick (1965) to suggest that pollen sterility per se raised yields on the average about 2%, but that Tms reduced yield by the same percentage. Duvick stressed the fact that in nonrestored hybrids, there was a statistically significant interaction between hybrids, cytoplasm and environments with respect to yield. This observation agreed with those of other workers (Grogan, 1956; Everett, 1960; Chinwuba et al., 1961; Noble and Russell, 1963).

Effect of cytoplasmic male sterility on plant characters

Some of the plant characters known to be affected by cytoplasmic male sterility other than yield are plant barrenness, number of leaves, silking rate and plant and ear heights.

Duvick (1958) found at an Illinois location that five out of six cytoplasmic male sterile genotypes had lower percentage barrenness than their fertile counterparts. Schwanke's (1965) study showed that male sterile genotypes had marked decreases in percent barrenness at 79,072 plants/hectare. Bruce et al. (1966) worked with southern prolific genotypes and found that the advantage of the cytoplasmic male sterile genotype was due to greater number of ears per

plant. The studies of Vincent (1968) and Sanford et al. (1965) all were in agreement with those of Duvick (1958) and Bruce et al. (1966) that male sterility reduced barrenness. The observations of Josephson and Kincer (1962) did not agree, however, with those of the others, as they found no difference in the number of ears per plant between male fertile and male sterile corn genotypes.

Leaf number and subsequently leaf area were shown by Duvick (1965) to be affected by cytoplasm. He found that Tms appeared to reduce leaf number per plant by 1-2%. Bruce et al. (1966) showed that leaf area index (LAI) was slightly less for male sterile genotypes than for their fertile counterparts at 47,839 plants/hectare.

The rate of silking has been shown to occur somewhat faster in some sterile genotypes than in fertile ones. Jones (1950) and Jones and Mangelsdorf (1951) showed that silking occurred at a faster average rate of 0.2 day in cytoplasmic male sterile plants. Marquez-Sanchez (1964) reported a faster average rate of 0.6 day. Stringfield (1958), on the other hand, failed to establish any significant cytoplasmic effect on silking date. Vincent (1968) showed that sterile genotypes silked 1.5 days faster than the fertile, although this difference was statistically insignificant. He also showed that there was a significant interaction of hybrids and sterility on days to reach 75% silking. Schwanke (1965) showed that six sterile genotypes silked faster than their

fertile counterparts by an average of 3.2 days.

Plant and ear height have been shown to be most consistently affected by sterile cytoplasm. Grogan and Sarvella (1964), Sarvella and Grogan (1965), and Bruce et al. (1966) showed that plant height in southern prolific hybrids was reduced primarily because of internodes length above the ear, the tassel culm, and, to a lesser extent, shorter internodes below the ear. Sarvella and Grogan (1965) explained that the shortening in parts occurred from 10-14 days after meiosis up to time of maturity. Vincent (1968) showed that genotypes 071 x 705 and B14 x 577 were significantly shorter and had their ear heights reduced for the sterile compared to the fertile. Grogan and Sarvella (1964) and Sarvella and Grogan (1965) suggested that the nonsequential shortening of the internodes in the sterile plants may have arisen from a temporary inhibition due to (depending on the genotype) hormonal regulation of cell elongation and/or division.

Different workers (Everett, 1960; Josephson and Kincer, 1962; Noble and Russell, 1963; Rogers and Edwardson, 1952) have compared normal and Texas cytoplasmic male hybrids for several other characteristics such as grain moisture, shelling percentage, stalk and root lodging, tendency to tiller and resistance to infection by H. triticum. There were no consistent cytoplasmic effects reported from these studies.

The plant factors prevalently thought to explain the process that brings about the superior yield performance of

cytoplasmic male sterile hybrids over their fertile counterparts have to do with: (a) tassel competition with ears, (b) tassel shading, and (c) stem sugar content and growth.

Chinwuba et al. (1961) and Schwanke (1965) had concluded from their studies that the response to male sterility seemed to be a decrease of the source of competition for photosynthates between the vegetative and reproductive tissues during tassel and ear emergence. This conclusion was in agreement with the earlier works of Duvick (1958) and Grogan et al. (1965). Bruce et al. (1966) reported that the male sterile hybrids consistently yielded more grain than the fertile counterparts primarily due to a greater number of second ears produced by these fertile hybrids. They also showed that the second-ear weight of male sterile prolific hybrids were significantly greater than those for the fertile ones. However, they found no consistent difference in the first ears.

Tassel vs ear concept

Sanford et al. (1964, 1965) tested the theory of competition between ear primodia and tassel (on prolific hybrids) by measuring the seasonal variations in the nitrogen uptake and utilization in corn. They found only small differences in nitrogen content of leaves and stems of barren plants when compared with the fertile plants. However, they found a considerably greater nitrogen level in fertile tassels before pollen shed, but following pollen shed, the differences

disappeared. From this work, Sanford et al. (1965) suggested that comparatively fewer ears per plant produced by male fertile hybrids were due to competition for nitrogen between the ear primodia and pollen produced by the fertile tassel. Bruce et al. (1966) also demonstrated that reduced levels of soil nitrogen affected ear diameter and ear length of fertile plants more than sterile strains. Cardwell (1967) did not find consistent differences in nitrate reductase activity of fertile and sterile strains.

Tassel shading

Increased radiant flux to leaves resulting from tassel removal has been suggested as a probable explanation for the yield increase from detasseling studies (Duncan et al., 1967; Hunter et al., 1969). Duncan et al. (1967) estimated yield reductions from tassel shading to range from 4-12% for population densities 24,710 to 73,130 plants/hectare. Hunter et al. (1969) found that detasseling resulted in significant yield increases and replacing detasseled tassels in the whorls produced yield similar to the not detasseled plants Furthermore, small tassel size, simulated by normal tassels which had their side branches removed (clipped off), also resulted in significant increase in yield over the normal tassel size.

Stem sugar and growth

Another possible explanation for the superior yield of male sterile corn over the fertile involves stem sugar content and growth. Cardwell (1967) observed that male sterile genotypes had higher percentages of sugar when compared with the fertile genotypes. He concluded that male sterility reduced the respiration needs of the plant, thus resulting in increased stalk sugar level and promoting ear development.

The main interest of the effect of cytoplasmic male sterility has been on grain yield, although effects of population and cytoplasmic male sterility on vegetative growth may have been studied. Brown et al. (1970) reported decreased leaf area but increased grain to stover ratio as plant density increased. Robinson and Murphy (1972) found that both forage and grain yields were significantly affected by nitrogen but not phosphorus or plant density. Leaf number (Duvick, 1965) and subsequently leaf area (Duvick, 1965; Bruce et al., 1966) were shown to be affected adversely by male sterility at high plant density. Cummins and McCullough (1971) compared male sterile and male fertile corn for silage and obtained different results for the two years of their study. They, however, concluded from their data that at the level of maturity studied, male sterile corn plants were comparable to male fertile corn for making silage.

MATERIALS AND METHODS

Two experiments, one each year, 1978 and 1979, were conducted on different sites at the Bruner farm of Iowa State University near Ames, Iowa.

The experimental sites were on a Nicollet-Webster and Nicollet silt-loam soil for 1978 and 1979, respectively. The land topography of these areas ranged between 0-2% slope. The pH ranges were moderately alkaline and the general fertility state of the sites were considered above average. The field used in 1978 was on a corn-soybean rotation, whereas the 1979 site was on a corn-oat-soybean rotation.

In each year, the field was fall plowed, at which time the P and K fertilizers were applied and incorporated as 0-26-26 mixture at the rate of 560 kg/ha. In spring, N was applied broadcast and disced in at the rate of 196 kg/ha. The source of N was urea. This gave an annual fertilizer dressing of 196-146-146 of N, P_2O_5, K_2O, respectively. A mixture of atrazine and alochlor was used as the weed control herbicide. This was applied to the field pre-emergence in the spring and at the rate of 2.24 kg/ha for each.

Single-cross hybrid seed corn (Zea mays) all supplied by Clyde Black and Son Inc. in Ames, were used for the studies both years. They were materials adapted to the Ames area.

In 1978, four single-cross hybrids carrying C or S cytoplasmic male sterility (Cms or Sms) and their normal fertile

counterparts were studied under three planting densities. The single-cross cytoplasmic male sterile hybrids and their fertile versions were: Wf9CmsHt x B37Ht(Cms) and Wf9Ht x B37Ht(fertile), B37CmsHt x B73Htht(Cms) and B37Ht x B73 (fertile); A554MysHtht x W182BN(Sms) and A554Ht x W182BN (fertile); Mo17WmsHtht x B73(Sms) and B73 x Mo17(fertile). Of the inbred components, Wf9 is considered intolerant to high plant density and tends to impart single earedness in its hybrids. A554 is an early hybrid for the Ames area. B37 x B73 and B73 x Mo17 are considered full and late season hybrids, respectively.

The population densities used in the 1978 experiment were 74,130, 54,362 and 34,594 plants/ha grown in 72.2 cm rows.

The main focus in this year's study was on grain and silage yields. A split-split plot experimental design with a randomized complete block arrangement was used for the experiment and was replicated four times. The four hybrids were the main treatments, the two cytoplasms the subtreatments, and three plant densities the sub-subtreatments. Six 10.4 meter long, 76.2 cm rows of corn constituted a sub-subplot. From here on, unless specified, the word plot will be used in reference to the sub-subplot.

Seeding of plots was done on June 1, 1978, at rates above the required plant densities, following normal seedbed preparation. Subsequently, plots were thinned to appropriate plant densities. Thinning was done after plants had attained about

38-53 cm in height.

Observation on the date of 75% silking was done by daily inspecting and taking counts of silked plants in each plot from a number of pretagged consecutive plants in a row of each plot. Inspection and counts were started following tassel emergence, and continued until a plot attained 75% silking.

The plots were sampled for silage yields, using a constant area of 0.0004 hectare. The sample for silage was taken after the grains had attained the black layer stage. Samples from border rows of each cytoplasm and hybrid taken periodically helped determine black layer appearance. All plants within the marked out area of each plot were cut about 5-8 cm from the ground. These were put together and weighed and the harvest fresh weight recorded. Then a composite sample of plants of each cytoplasm of each hybrid, across population, was taken for determination of percentage dry weight. The plants in the composite samples were chopped into convenient pieces, weighed, dried and reweighed for dry weight. The drying was done in a hot-air drying structure at $60^{o}C$. The dry weights were used to determine the moisture percentages of silage at harvest, and subsequently, to determine the dry matter yield of silage.

The final grain yield was taken from an area of 3.05 x 8.84 meters, involving only the four inner rows of each plot. Final counts of total stands, nubbins and barren plants, and

plants with double ears for each plot were obtained. All harvesting was by hand and harvested ears were weighed. Composite samples of ears of each cytoplasm of each hybrid across population was taken for dry weight and water percentage determination (% moisture is not affected by population, Lutz et al., 1971). Subsamples were weighed at harvest and again after drying to a constant weight at 60°C to determine moisture percent at harvest. The moisture percentages were used in converting fresh weight yield into dry weight yield. Also, they were used to compute the acre grain yields in bushels and subsequently, quintals per hectare of 15.5% moisture corn, by using the equation:

$$\frac{(\text{wt of corn harvested})(\text{acre factor})}{\begin{array}{c}(\text{pound of corn needed to equal one bushel of 15.5\% shelled corn at a given moisture percentage})\end{array}} = \begin{array}{l}\text{yield of corn of} \\ \text{15.5\% shelled corn}\end{array}$$

A table of moisture percentages (Table 1a) was used for this equation.

In 1979, field preparation, fertilization and herbicide applications were about the same as in 1978.

Four cytoplasmic male sterile hybrids and their fertile counterparts were also used. However, two of the hybrids used in 1978, A554MysHtht x W182BN and Mo17WmsHtht x B73, and their fertile versions were replaced by two other hybrids, B73CmsHt x N28Ht(Cms) and Wf9CmsHt x C103Ht(Cms) and their fertile counterparts, B73Ht x N28Ht and Wf9Ht x C103Ht, respectively. A Wf9 x C103 carrying Tms was included in the

Table 1a. Corn moisture conversion table[a,b,c]

Percent moisture	Pounds of ear corn required to yield 56 lbs (1 bu) of shelled corn at 15.5% moisture									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10	63.49	63.56	63.64	63.71	63.79	63.86	63.94	64.01	64.09	64.17
11	64.25	64.33	64.41	64.49	64.57	64.65	64.73	64.81	64.90	65.00
12	65.06	65.16	65.24	65.32	65.41	65.50	66.59	65.68	65.77	65.86
13	65.95	66.04	66.14	66.23	66.32	66.42	66.51	66.61	66.70	66.80
14	66.89	66.99	67.09	67.18	67.28	67.38	67.48	67.58	67.69	67.79
15	67.89	67.99	68.09	68.20	68.30	68.40	68.50	68.62	68.72	68.83
16	68.94	69.05	69.17	69.28	69.40	69.51	69.63	69.74	69.86	69.97
17	70.09	70.21	70.33	70.45	70.57	70.69	70.81	70.94	71.06	71.19
18	71.31	71.44	71.57	71.69	71.82	71.95	72.08	72.21	72.34	72.47
19	72.60	72.73	72.87	73.00	73.14	73.27	73.41	73.55	73.68	73.82
20	73.96	74.09	74.22	74.34	74.47	74.60	74.75	74.90	75.06	75.21
21	75.36	75.50	75.64	75.79	75.93	76.07	76.21	76.36	76.50	76.65
22	76.79	76.94	77.09	77.23	77.38	77.53	77.67	77.82	77.96	78.11
23	78.25	78.40	78.55	78.71	78.86	79.01	79.16	79.31	79.46	79.61
24	79.76	79.91	80.06	80.20	80.35	80.50	80.65	80.80	80.95	81.10
25	81.25	81.41	81.56	81.72	81.87	82.03	82.19	82.35	83.50	82.66
26	82.82	82.96	83.09	83.23	83.36	83.50	83.64	81.78	81.91	84.05
27	84.19	84.33	84.47	84.62	84.76	84.90	85.04	85.19	85.33	85.48
28	85.62	85.76	85.90	86.04	86.18	86.32	86.46	86.61	86.75	86.90
29	87.04	87.18	87.33	87.47	87.62	87.76	87.90	88.06	88.20	88.35
30	88.50	88.64	88.79	88.93	89.08	89.22	89.36	89.51	89.65	89.80

31	89.94	90.09	90.23	90.38	90.52	90.67	90.82	90.97	91.13	91.28
32	91.43	91.57	91.71	91.85	91.99	92.13	92.27	92.42	92.56	92.71
33	92.85	92.99	93.13	93.27	93.41	93.55	93.70	93.84	93.99	94.13
34	94.28	94.42	94.56	94.70	94.84	94.98	95.13	95.27	95.42	95.56
35	95.71	95.85	96.00	96.14	96.29	96.43	96.58	96.73	96.87	97.02
36	97.17	97.32	97.46	97.61	97.75	97.90	98.05	98.20	98.34	98.49
37	98.64	98.79	98.94	99.08	99.23	99.38	99.53	99.68	99.83	99.98
38	100.13	100.28	100.43	100.58	100.73	100.87	101.03	101.18	101.33	101.48
39	101.63	101.78	101.93	102.09	102.24	102.39	102.54	102.70	102.85	103.01
40	103.16	103.31	103.46	103.62	103.77	103.92	104.07	104.22	104.38	104.53
41	104.68	104.83	104.99	105.14	105.30	105.45	105.60	105.76	105.91	106.07
42	106.22	106.37	106.53	106.68	106.84	106.99	107.14	107.30	107.45	107.61
43	107.76	107.91	108.07	108.22	108.38	108.53	108.69	108.84	109.00	109.15
44	109.31	109.47	109.62	109.78	109.39	110.09	110.25	110.41	110.56	110.72
45	110.88	111.04	111.20	111.36	111.52	111.68	111.84	112.00	112.16	112.32

[a]The values in this table are based on an average of a very large number of samples of different hybrids grown in different years.

[b]Example on using table. Moisture percentage reads 28.7. How much ear corn is needed to yield 56 pounds of 15.5 percent corn? First, find 28 under column headed Percent moisture. Second, proceed to the right in the table opposite 28 until you are directly under 0.7. The answer is 86.61 pounds.

[c]J. A. Stritzel, Department of Agronomy, Iowa State University, mimeographed paper, Computing corn yields from demonstrations. 1961.

group of 1979 hybrids. The Wf9 x C103 single-cross hybrid was the most intolerant to high plant density among the hybrids used in 1979. It was also the most strongly single-eared hybrid. All the hybrids were regarded as full season hybrids.

Four population densities were used in the 1979 studies and consisted of 98,840, 79,072, 59,304 and 39,536 plants/ha. The experimental design was similar to that of 1978. The main focus was on grain yield and growth of individual plant parts. The following plant parts were measured in addition to grain yields:

1. Tassel length, fresh and dry weight
2. Top ear length, fresh and dry weight
3. Second ear length, fresh and dry weight
4. Stem sucrose content in percent (estimated by Brix reading on the second internodes above and below the ear)
5. Internode lengths for first, second and third internodes above and below the top ear; and fresh and dry weights of second internodes above and below top ear.

Other measurements made were:

6. Days to 75% pollen shed for fertile hybrids
7. Days to 75% silking for all hybrids
8. Number of nubbin and barren plants.

A split-split plot design arranged in randomized complete blocks was again used for the 1979 experiment. The main

treatment was hybrid, subtreatment was cytoplasm type and sub-subtreatment planting density. Six 76.2 cm rows of corn 9.75 meters long made up a sub-subplot.

Seeds of hybrids were machine planted on 22 May, 1979, following conventional seedbed preparation. Seeding rates exceeded the actual plant densities required. Thinning of plots to required planting density levels was done between 19 and 26 June, 1979, at which time plants were about 45.7 to 55.9 cm tall.

At anthesis, plots were scored for days to 75% pollen shed for fertile hybrids, and 75% silking for all hybrids. Similar arrangements and methods were used for scoring these characters as were used in the 1978 experiment.

On 23 July, 1979, about two weeks before anthesis, sampling of individual plants for the stipulated measurements was started, and was continued at feasible intervals through 17 August, 1979. The period of time for sampling was chosen because studies have referred to the period 3-2 weeks before anthesis to about a week after anthesis as a critical period of development of major yield determining parts of the corn, notably the tassel, ear and silk (Sass and Loeffel, 1959; Collins, 1963; Hanway, 1966). Two hybrids, B73CmsHt x N28Ht and Wf9CmsHt x C103Ht representing population tolerant and intolerant genotypes, respectively, and their fertile counterparts were involved in the individual plant measurements.

Sampling and Measurement Procedures

The samples for the individual plant parts measurements were taken randomly from specified and similar areas of all plots. Sampling was confined to the four inside rows of corn of each plot. Four plants per plot were used at first for a plot sample, but later three plants because of handling difficulties. The plants were cut and carried out from the plot to a wooden table. Here the leaves and leaf sheaths of each plant were stripped off. Then the lengths of the tassel (from just below the first branch), the first, second, and third internodes above and below the top ear, and the developing first ear, and later the second ear were measured in centimeters and recorded. Also, the fresh weights of the tassel and the second and/or first ear were taken after they had been severed from the rest of the stalk. The second internodes above and below the ear were also weighed after taking Brix readings on them. All weighed fresh samples were put into labelled paper bags and hot-air dried at $60^{o}C$ for dry weight determination.

Estimations of sucrose content of stems were made in the form of Brix density readings as reported by Lennox et al. (1935) and Van Reen and Singleton (1952). These workers found a high correlation between Brix reading and percent recoverable sucrose, particularly at sucrose levels above 1%. Brix readings were taken with a hand refractometer. In the proce-

dure, a 1-cm diameter cork bore was pushed through the mid-section of the internode. The plug that came out of it was squeezed in a pliers-like device to press out the juice. Then 4-5 drops of the juice were put on the prism surface of the refractometer and the Brix reading taken and recorded.

Due to field difficulties, it was not possible to get every replication into each sampling period of time (Table 1b). It was also difficult to make certain measurements in the early sampling time; as a result, some readings, like Brix, second ear, and second and third internode above, could not be obtained for the initial dates. However, these were taken care of in the statistical analysis by either statistically estimating values or leaving out these earliest times from the analysis.

Final plant stand per plot was taken at harvest time and also the numbers of nubbin, barren and two-eared plants were recorded. Two-earedness was so scanty that no analysis was done on it. Harvesting was by hand and was taken from a plot area of 1.52 x 7.62 meters, involving the inner two rows of each plot. Plot yields were weighed and the harvest weight recorded. Composite samples of ears for each density were taken for each hybrid across cytoplasm. The samples were dried to constant weights in hot-air driers at $60^{o}C$. The dry weights again were used to determine the moisture percentages of corn at harvest. The moisture percentages were used in computing corn yield per acre by using the equation and

Table 1b. Plan of plant measurement sampling

Periods	Replications[a] 1	2	3	4
1	X_1	X_2	X_3	
2	X_5		X_6	X_4
3	X_9	X_7		X_8
4		X_{11}	X_{10}	

[a] X_1-X_{11} represent dates on which samples were taken.

and moisture table (Table 1a) as menationed earlier and subsequently yields in quintals/ha were calculated.

Weather

The annual crop weather records for the State of Iowa considered 1978 and 1979 ideal years for corn growth for most parts of Iowa including the Ames area. The monthly and annual temperatures were slightly below normal. Top soil and subsoil moisture going into and during the seasons were said to be in good supply state wide.

Statistical Analysis

Data processing and computations were done at the Iowa State University Statistical Laboratory and Computation Center. Standard analyses of variance were computed for all variables

measured using the model:

$$Y_{ijkl} = \mu + B_i + A_j + \delta_{ij} + T_k + (AT)_{jk} + \gamma_{ijk} + S_l + (AS)_{jl} + (TS)_{kl} + (ATS)_{jkl} + E_{ijkl}$$

where:

Y_{ijkl} = the sub-subplot observation

μ = overall mean

B_i = block effect, i = 1,2,...,4

A_j = main treatment effect, j = 1,...2 or 1,2,...,4

δ_{ij} = error term associated with A and B

T_k = subtreatment effect, k = 1,...2

$(AT)_{jk}$ = mainplot x subtreatment interaction

δ_{ijk} = error associated with subtreatments

S_l = sub-subtreatment effect, l = 1,2,...,4

$(AS)_{jl}$ = main treatment x sub-subtreatment interaction

$(TS)_{kl}$ = subtreatment x sub-subtreatment interactions

$(ATS)_{mkl}$ = main treatment x subtreatment x sub-subtreatment interactions

E_{ijkl} = error associated with Y_{ijkl} observation (i.e., overall error).

A sample skeletal analysis of variance based on the above model is given in Table 2 for 1978 and 1979 plot data.

Duncan's multiple range test was used to group some means to establish meaningful levels of differences. A T-test was carried out where Duncan's could not delineate differences.

Because of the irregularity of replication distribution

Table 2. Skeletal analysis of variance for 1978/79 plot data

Source of variation	Degrees of freedom 1978	1979
Replication (R)	3	3
Hybrid (H)	3	3
Error a (R x H)	9	9
Cytoplasm (C)	1	1
Hybrid x cytoplasm (Error b)	3	3
R x H x C	12	12
Density	2	3
H x density	6	9
C x density	2	3
H x C x density	6	9
Error c	48	72

in individual plant part measurements, a direct regression of data on time (dates) could not reasonably be done; rather, values of replications within each time period were analyzed separately to determine responses at that period in order to get a continuous trend of effect with time. Plots of the effect of density on the cytoplasm of each hybrid were made over periods.

Comparisons involving the genotype with regard to corn yield was limited to within the Wf9 x C103 hybrid.

EXPERIMENTAL RESULTS

Grain and Silage Yields

In both years of the experiment, corn grain yields varied significantly among hybrids, between cytoplasm type and with plant density, all at the 1% level of probability (Tables 3 and 4).

Grain yields of hybrid in 1978 calculated over all cytoplasm and plant densities ranged from 48.0 quintals/hectare (q/ha) to 65.8 q/ha and from 51.9 to 63.3 q/ha for plant densities (Table 5).

The mean grain yield for cytoplasms over all hybrids and densities was significantly greater for the sterile, 61.3 q/ha, than for the fertile cytoplasm which had 55.6 q/ha.

The interactions between hybrid and plant density, hybrid and cytoplasm, and cytoplasm and density for grain yields were also statistically significant, hybrid x density and hybrid x cytoplasm at the 1% level and cytoplasm x density at the 5% level of significance.

Figure 1 shows the yields of hybrids as plant density was increased from 34,594 to 74,130 plants/ha. A declining rate of increase is observed in all hybrids as plant density was increased, but the amount of decline varied with hybrid.

The hybrid x cytoplasm interaction is shown in Table 5. The least response from sterile cytoplasm was with A554 x W182 and the greatest response was with Mo17 x B73.

Table 3. Mean squares for days to 75% silking, barren and nubbin plants, silage yield, harvest stand count, and grain yield on four hybrids with two cytoplasms and three plant densities (1978)

Source	df	75% silking	Barrenness	Silage yield	Harvest stand	Grain yield
Reps (R)	3	31.22	92.40	8.49	38.52	80.51
Hybrid (H)	3	717.69**	105.84	65.22**	274.36*	2420.84**
Error a	9	3.47	49.39	2.25	40.70	21.60
Cytoplasm (C)	1	4.16	30.37	2.82	77.04	688.01**
H x C	3	0.63	58.73	1.89	29.56	108.68**
Error b	12	0.54	30.95**	2.17	26.99	6.28
Density (D)	2	27.32**	634.88**	111.56**	73425.69**	749.17**
H x D	6	2.22**	81.89**	4.32	231.60**	47.99**
C x D	2	0.51	3.96	0.12	30.94	38.36*
H x C x D	6	1.94*	30.95	0.90	101.51*	14.46
Error c	48	0.62	24.32	2.47	35.63	10.21

*Significant difference at P = .05.

**Significant difference at P = .01.

Table 4. Mean squares for days to 75% silking, barrenness, stand count at harvest, and grain yield of four corn hybrids with two cytoplasms and at four plant densities (1979)

Source	df	75% silking	Barrenness	Stand count	Grain yield
Rep (R)	3	11.43	25.35	84.39	29.71
Hybrid (H)	3	13.26**	476.60**	202.43**	159.11**
Error a	9	1.24	24.42	14.66	5.19
Cytoplasm (C)	1	1.85	795.00**	3.12	466.65**
H x C	3	6.76	370.17**	36.27	99.21**
Error b	12	2.15	39.73	23.88	5.46
Density (D)	3	40.97**	4020.43**	23081.87**	177.56**
H x D	9	2.30	261.83**	60.20*	88.32**
C x D	3	7.94**	244.17**	60.41	63.35**
H x C x D	9	2.39	167.46**	26.95	10.24
Error c	72	1.35	33.73	24.57	8.47

*Significant difference at P = .05.

**Significant difference at P = .01.

Table 5. Grain yield of four hybrids each with two cytoplasms at three plant densities (1978)[a]

Hybrid	Cytoplasm	Plant density (plants/ha) 34,594	54,362	74,130	Mean
		q/ha			
Wf9 x B37	Fertile	55.57a	56.30b	57.49b	56.45
	Sterile	56.70a	62.33a	62.20a	50.41
	Mean	56.13	59.31	59.84	58.43c
B37 x B73	Fertile	51.97a	62.57a	63.72b	59.42
	Sterile	54.20a	64.27a	72.58a	63.68
	Mean	53.08	63.42	68.15	61.55b
A554 x W182	Fertile	40.19a	50.73a	52.25a	47.72
	Sterile	42.35a	48.72a	53.86a	48.04
	Mean	41.27	49.73	53.05	48.02d
Mo17 x B73	Fertile	53.37b	50.23b	62.89b	58.83
	Sterile	61.19a	75.87a	81.43a	72.83
	Mean	57.28	68.05	72.16	65.83a
Mean all fertile		50.27	57.46	59.09	55.60b
Mean all sterile		53.61	62.80	67.52	61.30a
Overall mean		51.94b	60.13a	63.30a	

[a]Means followed by the same letter are not statistically significant (P = .05). Letters are applied to means for the main effects of hybrid, cytoplasm and plant density and for cytoplasms within a density and hybrid.

Mean yields for the cytoplasm by density interactions are shown in Table 5 and diagrammed in Figure 2. At a plant density of 34,594 the response to sterile cytoplasm was 3.34 q/ha and at the greatest plant density the response was 8.43 q/ha more than the sterile.

The Duncan's multiple range values calculated to compare cytoplasms within a hybrid and plant density showed that

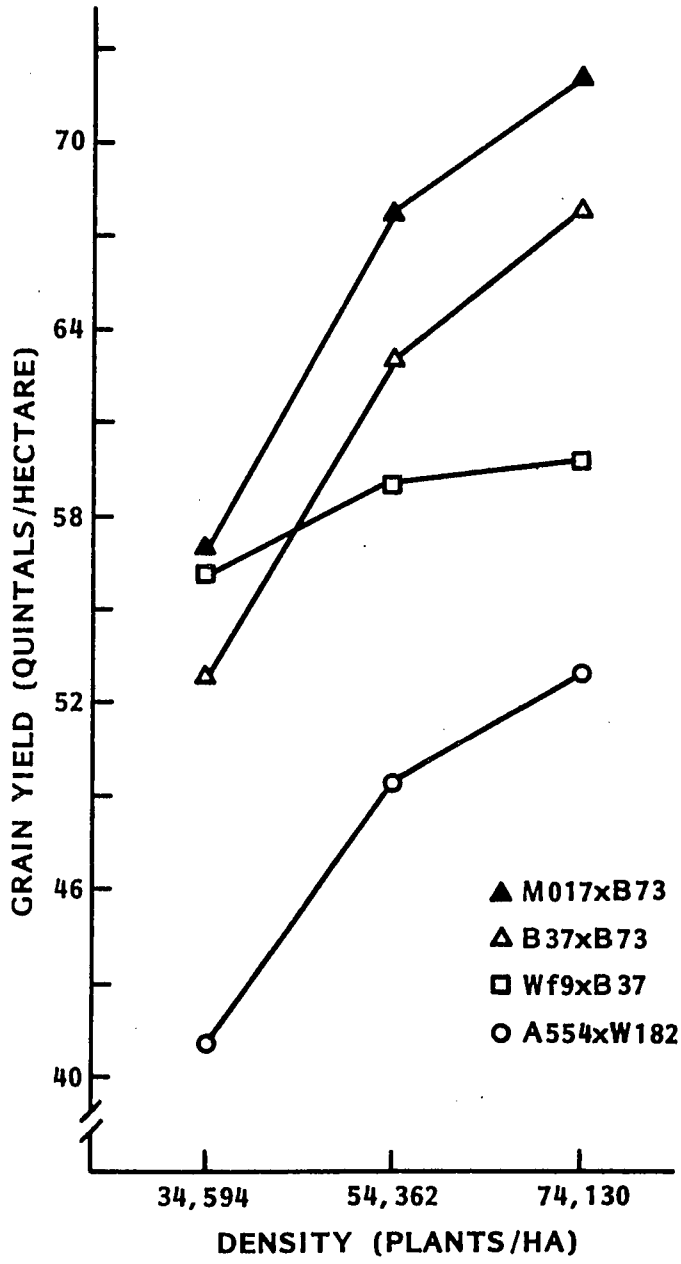


Figure 1. Grain yield for four corn hybrids as affected by plant densities (1978)

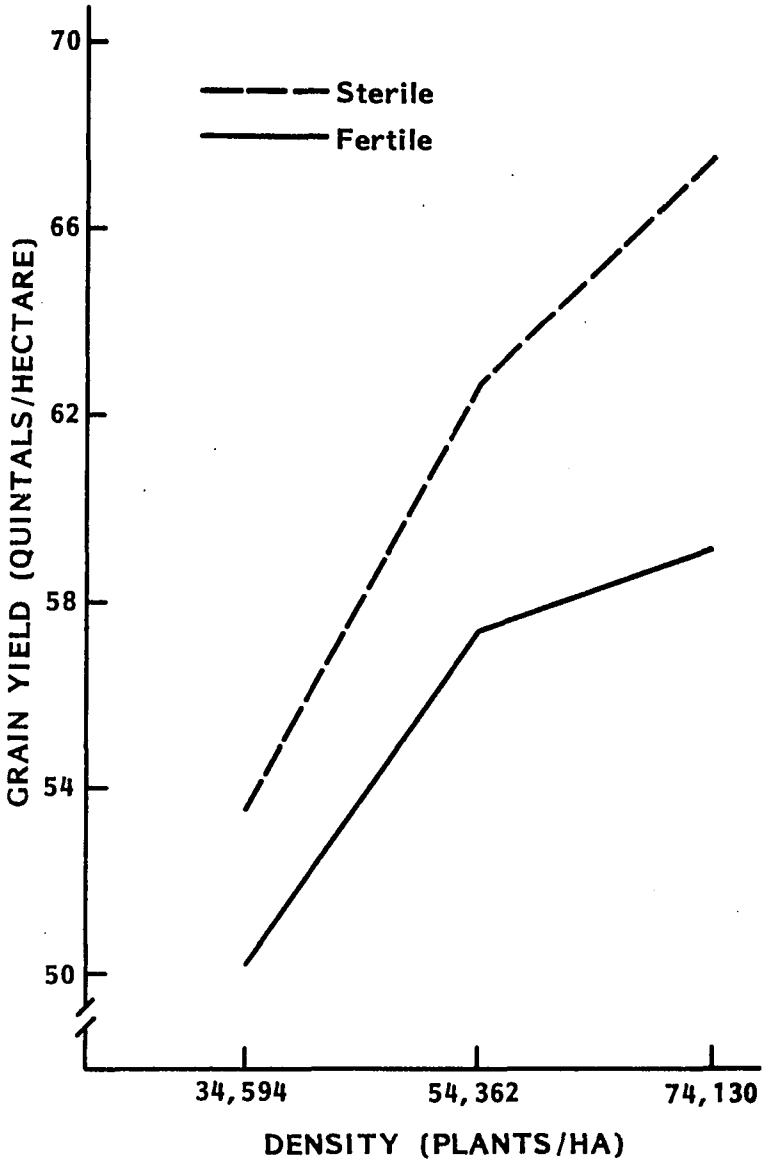


Figure 2. Grain yield of male sterile and male fertile cytoplasms as affected by plant densities (1978)

A554 x W182 had no response to cytoplasm at any plant density level, whereas for Mo17 x B73 the sterile yielded more than the fertile at all plant densities. The two other hybrids showed intermediate effects of cytoplasm.

Silage yields in 1978 statistically varied significantly at the 1% level with hybrid and with plant density as shown in Table 3. On dry weight basis, Wf9 x B37 was the greatest silage yielder, but was not significantly greater than B37 x B73 or Mo17 x B73. These three, however, yielded significantly greater than A554 x W182. Yields of hybrids were significantly increased by increasing plant density as presented in Table 6.

The mean yields of fertile and sterile cytoplasms across hybrid and density did not vary significantly.

Neither the hybrid by density, hybrid by cytoplasm nor cytoplasm by density interactions were statistically significant. The Duncan's multiple range letters for cytoplasm within a hybrid and plant density help show why there were no significant interactions.

The effects of hybrid, density and cytoplasm on grain yield for the 1979 experiment are given in Table 7. Grain yields of hybrids varied from 95.8 q/ha for B73 x N28 to 87.9 q/ha for Wf9 x C103.

Increasing plant density from 39,536 to 59,306 plants/ha significantly increased yield by 5.9 q/ha. A further increase in plant density to 79,072 decreased yield 5 q/ha compared to

Table 6. Silage yield of four hybrids with two cytoplasms at three plant densities (1978)[a]

Hybrid	Cytoplasm	Plant density (plants/ha) 34,594	54,362	74,130	Mean
		----------ton/ha----------			
Wf9 x B37	Fertile	11.52a	15.24a	15.10a	13.95
	Sterile	12.06a	15.41a	15.91a	14.46
	Mean	11.79	15.33	15.50	14.21a
B37 x B73	Fertile	11.71a	14.52a	14.94a	13.72
	Sterile	11.17a	13.89a	14.87a	13.31
	Mean	11.44	14.21	14.91	13.52a
A554 x W182	Fertile	9.55a	9.36a	12.25a	10.39
	Sterile	9.38a	10.92a	11.88a	10.73
	Mean	9.47	10.14	12.06	10.56b
Mo17 x B73	Fertile	10.48a	13.04a	15.17a	12.90
	Sterile	11.55a	13.78a	16.06a	13.80
	Mean	11.02	13.41	15.62	13.35a
Mean all fertile		10.82	13.04	14.36	12.74a
Mean all sterile		11.04	13.50	14.68	13.07a
Overall mean		10.93b	13.27ab	14.52a	

[a]Means followed by the same letter are not statistically significant (P = .05). Letters are applied to means for the main effects of hybrid, cytoplasm and plant density and for cytoplasms within a density and hybrid.

the 59,304 plant density and the least yield was obtained at the highest density of 98,840 plants/ha.

The mean grain yield for hybrids with sterile cytoplasm was significantly greater than that of their fertile counterparts by about 9.1 q/ha.

The interactions of hybrid by density, cytoplasm by

Table 7. Grain yield of four hybrids with two cytoplasms at four plant densities (1979)[a]

Hybrid	Cytoplasm	Plant density (plants/ha) 35,536	59,304	79,072	98,840	Mean
		q/ha				
Wf9 X B37	Fertile	89.69b	95.50a	82.55b	76.73b	86.12
	Sterile	94.13a	92.15b	93.12a	91.75a	92.79
	Mean	91.91	93.82	87.84	84.24	89.45bc
B37 x B73	Fertile	89.08b	93.51b	91.92b	80.90b	88.85
	Sterile	92.83a	100.30a	104.42a	90.66a	97.05
	Mean	90.96	96.90	98.17	85.78	92.95ab
B73 x N28	Fertile	87.83a	103.38a	97.66a	91.86b	95.18
	Sterile	87.20a	101.33a	98.41a	98.45a	96.35
	Mean	87.52	102.36	98.04	95.15	95.77a
Wf9 x C103	Fertile	90.85b	93.77b	74.73b	51.57b	77.73
	Sterile	103.20a	102.13a	98.36a	88.89a	98.15
	Mean	97.03	97.95	86.55	70.23	87.94c
Mean all fertile		89.36	96.54	86.72	75.27	86.97b
Mean all sterile		94.34	98.98	98.58	92.43	98.08a
Overall mean		91.85b	97.76a	92.65ab	83.85c	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effects of hybrid, cytoplasm and density and for cytoplasms within a density and hybrid.

density and hybrid by cytoplasm were significant at the 1% level. Figure 3 shows the interaction of hybrid and plant density. Each hybrid varied somewhat differently with plant density. Wf9 x C103 gave the best yields at the two lowest plant densities (39,536 and 59,304 plants/ha) and showed a drastic decrease in yield at the highest plant density (98,840 plants/ha). Its yield at the low plant density was 5.12 q/ha greater than the yield of Wf9 x B73, the next greatest yielder at the lowest plant density. B73 x N28 gave the lowest yield of all hybrids at 39,536 plants/ha and the greatest yield at all other density levels. Its greatest yield was at 59,304 plants/ha. B37 x B73 gave the second to the least yield of all hybrids at 39,536 plants/ha and second to the greatest yield at 98,840 plants/ha. Its greatest yield was at 79,072 plants/ha. Wf9 x B73 gave the second best yield at 39,536 plants/ha and the second lowest yield at 98,840 plants/ha. Its greatest yield was at 59,306 plants/ha.

The cytoplasm by density interaction is presented in Figure 4. Yield increased in both fertile and sterile cytoplasm as plant density increased to 59,304 plants/ha. From that point there was a very sharp decline in yield for the fertile cytoplasm, but a more gradual decline for the sterile cytoplasm. The yield advantage of the sterile cytoplasm over the fertile increased from 2.44 q/ha at 59,304 to 11.86 q/ha at 79,072 and to 17.16 q/ha at 98,840 plants/ha.

The interaction of hybrid and cytoplasm on yield of corn

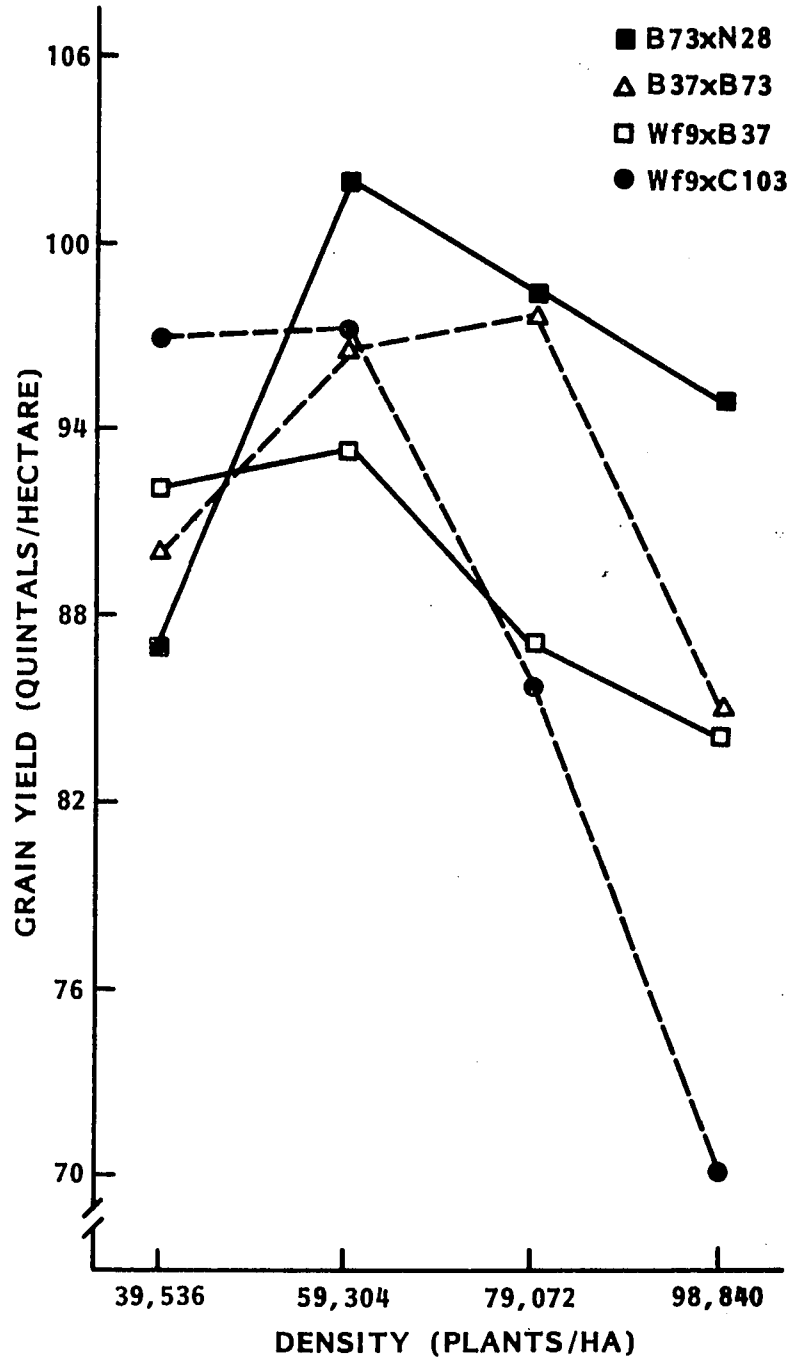


Figure 3. Grain yield of four hybrids as affected by plant densities (1979)

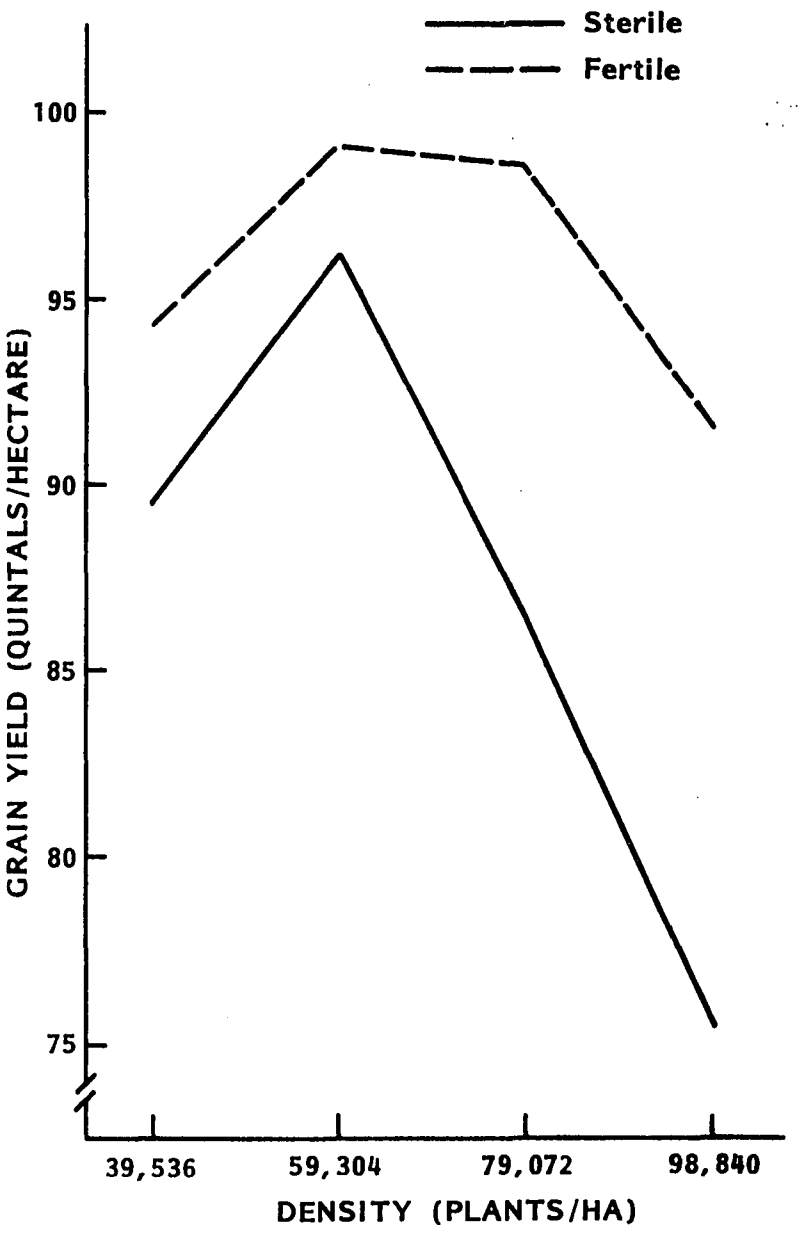


Figure 4. Grain yield of male sterile and male fertile cytoplasms as affected by plant densities (1979)

hybrids showed that the yield advantage of the sterile cytoplasm was 1.17, 4.67, 8.20 and 21.42 q/ha for B73 x N28, Wf9 x B37, B37 x B73 and Wf9 x C103, respectively.

Days to 75% Silking

In 1978, the number of days to 75% silking was affected significantly at the 1% level by hybrid and plant density, and at the 5% level by cytoplasm. There also was a significant hybrid by density interaction, but no interaction was observed either between cytoplasm and density or hybrid and density (Table 3).

The mean number of days to 75% silking for hybrids, cytoplasms and densities are presented in Table 8. Hybrids Wf9 x B37, B37 x B73 and Mo17 x B73 did not vary in their number of days to 75% silking, but these three averaged about 11 days later than A554 x W182. The 34,594 plants/ha density attained 75% silking significantly earlier than the 74,130 plants/ha density by about 0.84 days, but not significantly earlier than 54,362 plants/ha density. Plant density of 54,362 and 74,130 plants/ha did not differ significantly in days to 75% silking. Plants with sterile cytoplasm reached 75% silking earlier than the fertile plants by a significant 0.42 day.

Figure 5 shows the hybrid x density interactions. Plant density level influenced the time of 75% silking of A554 x W182 less than for the others. The three-way interaction was

Table 8. Mean number of days to 75% silking for four hybrids of two cytoplasms at three plant densities (1978)[a]

Hybrid	Cytoplasm	Plant density (plants/ha) 34,594	54,362	74,130	Mean
		----------days----------			
Wf9 x B37	Fertile	67.00a	69.25a	70.00a	68.75
	Sterile	67.75a	68.00a	69.50a	68.42
	Mean	67.38	68.63	69.75	68.59a
B37 x B73	Fertile	69.50a	69.25a	71.00a	69.62
	Sterile	67.75b	70.25a	70.00a	69.33
	Mean	68.63	69.75	70.50	69.63a
A554 x W102	Fertile	58.25a	58.25a	58.75a	58.42
	Sterile	58.25a	58.50a	58.50a	58.42
	Mean	58.25	58.38	58.63	58.42b
Mo17 x B73	Fertile	68.50a	70.25a	71.50a	70.08
	Sterile	68.00a	69.50a	70.50a	69.33
	Mean	68125	69.88	71.00	69.71a
Mean all fertile		65.81	66.75	67.81	66.79a
Mean all sterile		65.44	66.56	67.12	66.37b
Overall mean		66.62b	66.65b	67.46a	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effects of hybrid, cytoplasm and density and for cytoplasms within a density and hybrid.

significant at the 5% level. Neither plant density nor type of cytoplasm affected time of 75% silking for A554 x W182, whereas for the other hybrids, the fertile cytoplasms were later than the sterile, especially at the higher plant densities.

In the 1979 experiment, number of days to silking differed significantly at the 1% level for hybrids and for plant density

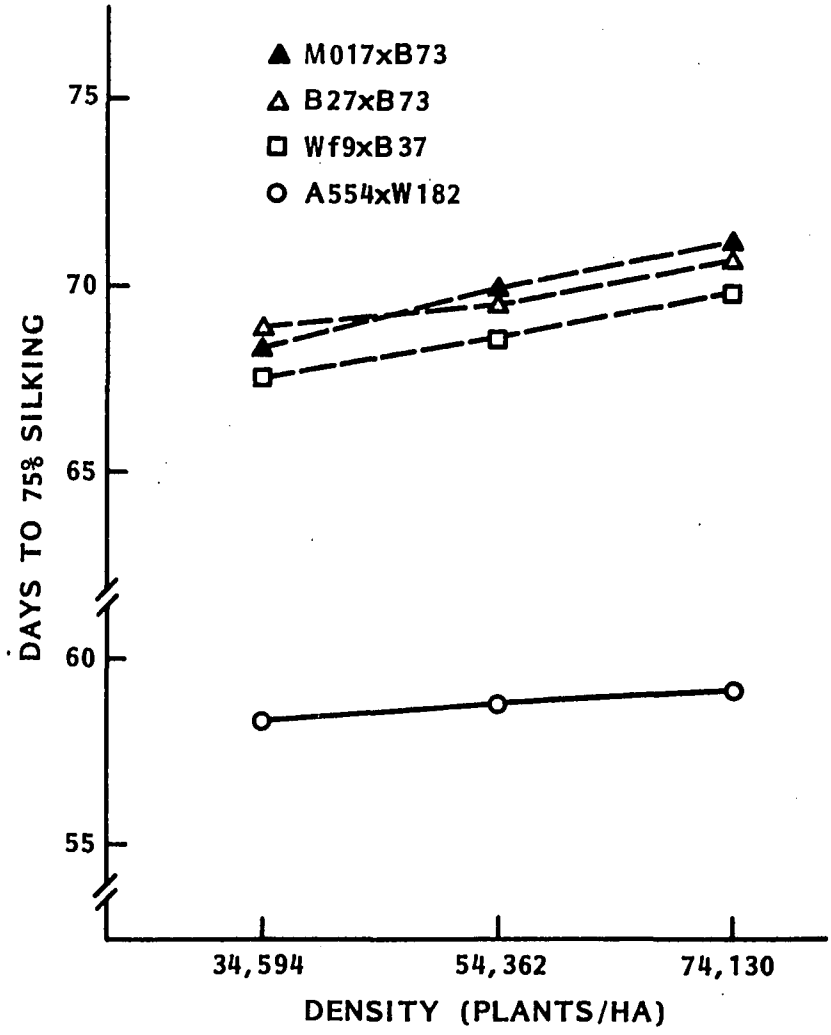


Figure 5. Silking time of four corn hybrids as affected by plant densities (1978)

but not for cytoplasm (Table 4).

Wf9 x C103 differed significantly from the other three hybrids by an average of 1.01 days delay in attaining 75% silking. The three hybrids, Wf9 x B37, B37 x B73 and B73 x N28 did not vary for this attribute as seen in Table 9.

The effect of plant density on days to silking did not vary significantly for densities 59,304, 79,072 and 98,840 plants/ha (Table 9). The effect of 39,536 plants/ha was not significantly different from the densities 59,304 and 79,072 plants/ha but 39,536 plants/ha reached 75% silking significantly earlier than the 98,840 density by 2.73 days.

The main effect of cytoplasm was not significant, but the cytoplasm x density interaction was significant at the 1% level. The influence of plant density in delaying days to 75% silking was greater with fertile than with the sterile cytoplasm. Number of days to 75% silking increased in the fertile cytoplasm as plant density increased. At 98,840 plants/ha there was a 1.45 days greater delay for the fertile than for the sterile cytoplasm, whereas at the lowest plant density the sterile cytoplasm averaged 0.37 day latter than the fertile (Table 9).

The Duncan's multiple range tests for cytoplasms within a hybrid and plant density show the tolerance to plant density of B73 x N28 and in contrast the intolerance of Wf9 x C103.

Table 9. Mean number of days to 75% silking for four corn hybrids with two cytoplasms at four plant densities (1979)[a]

Hybrid	Cytoplasm	Plant density (plants/ha) 39,536	59,204	79,072	98,840	Mean
		days				
Wf9 x B37	Fertile	73.75a	73.75a	75.00a	77.50a	75.00
	Sterile	73.00a	75.25a	74.50a	76.00a	74.69
	Mean	73.38	74.50	74.75	76.75	74.85b
B37 x B73	Fertile	73.75a	75.25a	75.25a	76.50a	75.19
	Sterile	75.25a	76.00a	75.25a	76.25a	75.69
	Mean	74.50	75.63	75.25	76.38	75.44b
B73 x N28	Fertile	73.75a	75.25a	75.30a	76.25a	75.14
	Sterile	74.50a	75.25a	76.00a	76.25a	75.50
	Mean	74.14	75.25	75.65	76.25	75.32b
Wf9 x C103	Fertile	74.50a	75.25a	78.75a	80.05a	77.14
	Sterile	74.50a	76.00a	76.00b	76.00b	76.63
	Mean	74.50	75.63	77.38	78.03	76.38a
Mean all fertile		73.94	74.88	76.08	77.58	76.62a
Mean all sterile		74.31	75.68	75.44	76.13	75.38a
Overall mean		74.13b	75.25ab	76.76ab	76.86a	

[a] Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effects of hybrid, cytoplasm, and density, and for cytoplasms within a density and hybrid.

Plant Barrenness

In 1978, barren plants were counted together with plants with nubbin ears and the total treated as barren plants. Barrenness in the 1978 experiment was affected at the 1% level of significance by density of planting and there was also a hybrid by density interaction at the 1% level of statistical difference (Table 3).

The plant density of 34,594 plants/ha differed from the 74,130 plants/ha by 3.78% as shown in Table 10. The 54,362 plant density did not differ significantly from the 39,594 and 74,130 plants/ha densities.

The hybrid by density interaction (Table 10) shows that plant density influenced some hybrids more than they did others. B37 x B73 appeared to be the least affected with change in density and Wf9 x B37 was the most affected by plant density changes. The statistical tests for the cytoplasm effects within a hybrid and density mainly show the intolerance of the fertile cytoplasm of Wf9 x B37 at high plant density.

All the main effects of hybrids, plant densities, and cytoplasms on barrenness as well as their interactions were significant at the 1% level in 1979 (Table 4). The effects of hybrid, plant density and cytoplasm on percentage barrenness are as presented in Table 11.

Wf9 x C103 gave the highest percentage of barren plants, 15.9%, and varied significantly in this respect from each of

Table 10. Percent barren and nubbin plants for four corn hybrids with two cytoplasms at three plant densities (1978)[a]

Hybrid	Cytoplasm	Plant density (plants/ha) 34,594	54,362	74,130	Mean
		----------%----------			
Wf9 x B37	Fertile	1.93a	9.17a	12.31a	7.80
	Sterile	0.56a	4.18a	7.52a	4.09
	Mean	1.24	6.67	9.91	5.94a
B37 x B73	Fertile	1.70a	5.85a	1.80a	3.12
	Sterile	4.32a	4.01a	4.39a	4.24
	Mean	3.01	4.93	3.09	3.68a
A554 x W182	Fertile	4.86a	2.83a	4.53a	4.07
	Sterile	0.00a	5.54a	4.87a	3.47
	Mean	2.43	4.18	4.70	3.77a
Mo17 x B73	Fertile	1.38a	2.86a	5.63a	3.29
	Sterile	1.93a	1.74a	5.83a	3.17
	Mean	1.65	2.30	5.73	3.23a
Mean all fertile		2.47	5.18	6.07	4.57a
Mean all sterile		1.70	3.87	5.65	3.74a
Overall mean		2.08b	4.50ab	5.86a	

[a]Means followed by the same letters are not statistically different (P = .05). Letters are applied to means for the main effects of hybrid, cytoplasm and density, and for cytoplasms within a density and hybrid.

the other hybrids. B37 x B73 and B73 x N28 with 8.28 and 7%, respectively did not vary in their percentages of barren plants. Wf9 x B37 was intermediate in barrenness.

Percent barrenness at 39,536 plants/ha (1%), and 59,304 plants/ha (4.6%), each varied significantly from percent barrenness at 79,072 and 98,840 plants/ha, but were not

Table 11. Percent barrenness of four corn hybrids each with two cytoplasms at four plant densities (1979)[a]

Hybrid	Cytoplasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		% barrenness				
Wf9 x B37	Fertile	1.08a	5.92a	20.99a	30.63a	14.66
	Sterile	0.53a	9.71a	12.92b	19.17b	10.58
	Mean	0.81	7.82	16.96	24.90	12.62b
B37 x B73	Fertile	0.53a	4.04a	11.05a	19.28a	8.72
	Sterile	0.00a	1.82a	11.39a	18.16a	7.84
	Mean	0.27	2.93	11.22	18.72	8.28c
B73 x N28	Fertile	2.25a	4.55a	13.24a	9.67a	7.43
	Sterile	2.11a	3.26a	8.01a	12.90a	6.57
	Mean	2.18	3.91	10.63	11.29	7.00c
Wf9 x C103	Fertile	1.67a	6.93a	28.45a	58.04a	23.77
	Sterile	0.00a	0.79a	11.65b	19.76b	8.05
	Mean	0.80	3.86	20.05	38.90	15.90a
Mean all fertile		1.38	5.36	18.44	29.40	13.64a
Mean all sterile		0.66	3.89	10.99	17.50	8.26b
Overall mean		1.02c	4.63c	14.71a	23.45a	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effects of hybrid, cytoplasm and density and for cytoplasms within a density and hybrid.

significantly different between themselves. Barrenness at 79,072 plants/ha (14.7%) was not significantly different from that at 98,840 plants/ha (23.4%).

The fertile cytoplasm had about 6.3% more barren plants than the sterile cytoplasm. This difference was significant at the 1% level.

Figure 6 shows the interaction effects of hybrid and density on plant barrenness. Barrenness increased with increase in plant density but varied with hybrid, especially at the higher densities. Wf9 x C103 had the highest percentage of barrenness (20 and 38.9%) at the two highest plant densities. B37 x N28 had the least barrenness at the two high densities (10.6 and 11.3%).

The interaction effects of cytoplasm and plant densities is graphed in Figure 7. The difference in percentage barrenness of fertile and sterile cytoplasm increased as plant density increased. As plant density was increased from 59,304 to 79,072 and 98,840 plants/ha, barrenness increased 13 and 22% for the fertile and only 7.1 and 13.6% for the sterile.

The interaction of hybrid and cytoplasm is given in Table 11. The sterile cytoplasm resulted in a lower percentage of barrenness, but varied with hybrid. Wf9 x C103 was the most responsive to this interaction effect and B73 x N28 was the least.

The comparison between cytoplasm within a hybrid and plant density showed no effects at all densities for B73 x

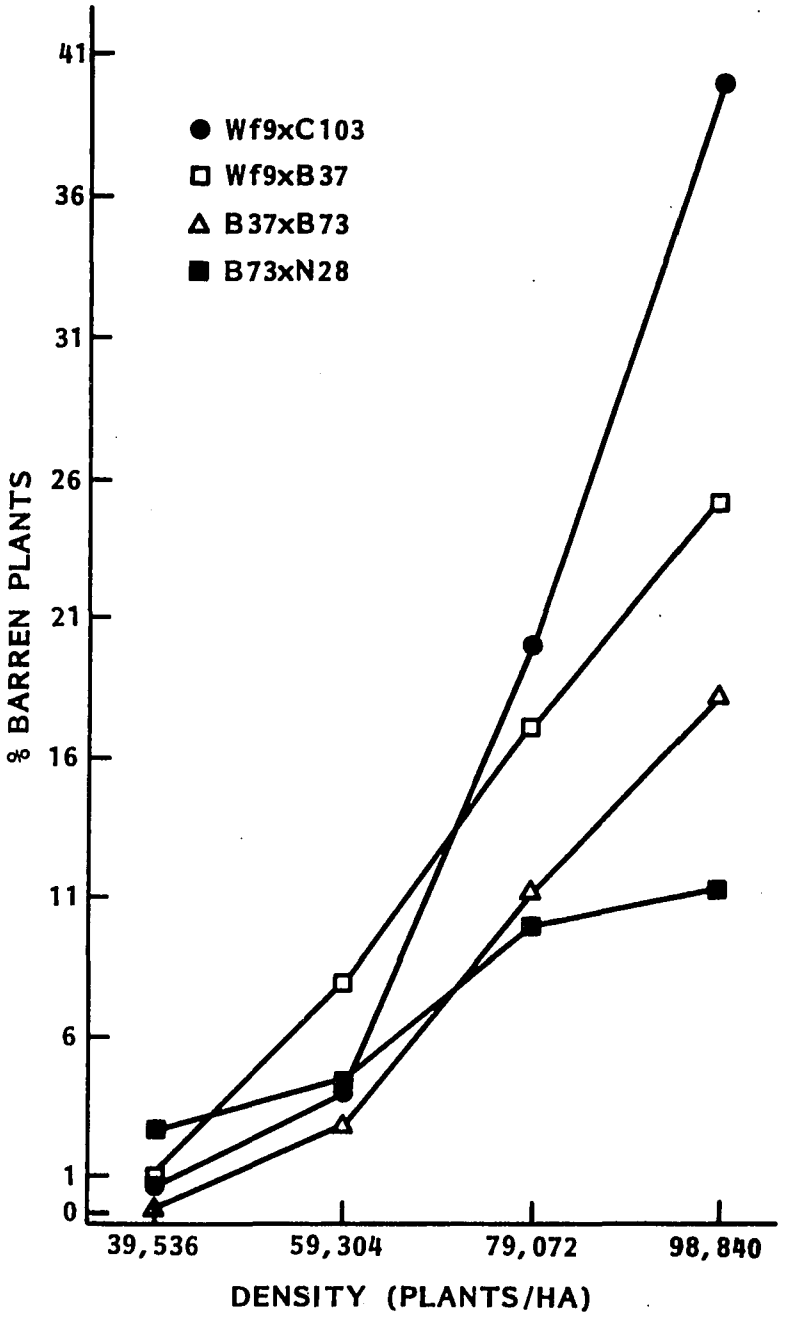


Figure 6. Plant barrenness in four corn hybrids as affected by plant densities (1979)

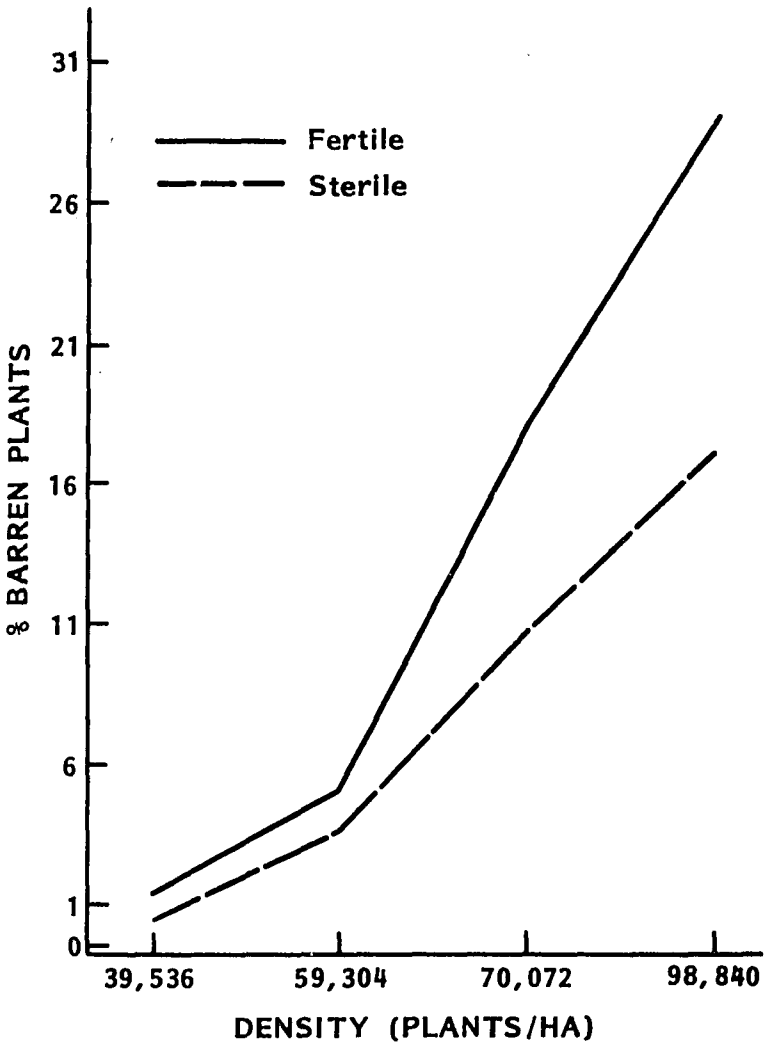


Figure 7. Plant barrenness of male fertile and male sterile cytoplasms as affected by plant densities (1979)

N28 and for B37 x B73, whereas for Wf9 x B37 and Wf9 x C103 the advantage of sterile cytoplasm increased as plant density increased. The three-way interaction also was highly significant.

Plant Stand at Harvest

In 1978, mean plant stand at harvest was affected significantly at the 1% level by plant density and at the 5% level by hybrid. There was no significant differences due to type of cytoplasm. There was a hybrid by density interaction significant at the 1% level and a hybrid by cytoplasm by density interaction significant at the 5% level (Table 3).

The mean number of plants at harvest varied with plant density, with significantly higher number of plants for the higher densities. B37 x B73 and Mo17 x B73 had about the same number of plants at harvest (141.96 and 140.55, respectively) and together differed from Wf9 x B37 and A554 x W182 which also had similar numbers (137.2 and 134.5, respectively) (Table 12).

The interaction of hybrid and density showed some variation between hybrids in the stand at harvest at the highest plant density, whereas at the lowest plant density the hybrids had similar stands. The two most tolerant to density hybrids maintained the greater stand at harvest, and therefore, their tolerance to plant density was tested more rigorously than the other two hybrds. The three-way interaction was

Table 12. Mean stand count of plants at harvest for four hybrids, two cytoplasms and three plant densities (1978)[a]

Hybrid	Cytoplasm	Plant density (plants/ha) 34,594	54.362	74,130	Mean
		---------number of plants----------			
Wf9 x B37	Fertile	90.50a	144.50a	178.75a	137.92
	Sterile	89.25a	137.50a	182.76a	136.50
	Mean	89.88	141.00	180.75	137.21b
B37 x B73	Fertile	88.00a	145.75a	194.25a	142.67
	Sterile	86.75a	143.25a	193.75a	141.25
	Mean	87.38	144.50	194.00	141.96a
A554 x W182	Fertile	87.50a	141.25a	182.00a	136.92
	Sterile	87.50a	144.50a	164.25b	132.08
	Mean	87.50	142.88	173.13	134.50b
Mo17 x B73	Fertile	90.75a	139.75a	190.75a	140.42
	Sterile	90.50a	143.50a	188.50a	140.83
	Mean	90.63	141.38	189.63	140.55a
Mean all fertile		89.19	142.81	186.44	139.48a
Mean all sterile		88.50	142.19	182.31	137.60a
Overall mean		88.85c	142.50b	184.38a	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effects of hybrid, cytoplasm and density and for cytoplasms within a density.

significant.

The mean number of plants in 1979 was significantly different for each of the plant densities as would be expected (Table 13). B37 x B73 and B73 x N28 were not significantly different in stand count at harvest and also Wf9 x B73 and Wf9 x C103 were also not different, but the two groups were significantly

Table 13. Mean stand count at harvest for four hybrids, two cytoplasms, and four plant densities (1979)[a]

Hybrid	Cytoplasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		number of plants				
Wf9 x B37	Fertile	46.50a	71.75a	85.75a	107.75a	77.93
	Sterile	47.00a	69.50a	89.00a	103.00a	77.13
	Mean	46.75	70.63	87.38	105.38	77.52b
B37 x B73	Fertile	47.50a	68.00a	92.75b	111.50a	79.94
	Sterile	47.00a	68.75a	101.00a	117.00a	83.44
	Mean	47.25	68.38	96.88	114.25	81.69a
B73 x N28	Fertile	44.50a	77.00a	93.25a	106.26a	80.25
	Sterile	47.50a	69.00a	90.50a	110.00a	79.25
	Mean	46.00	73.00	91.88	108.13	79.75a
Wf9 x C103	Fertile	45.00a	68.50a	87.00a	104.00a	76.13
	Sterile	45.25a	63.25a	88.00a	106.00a	75.63
	Mean	45.13	65.88	87.50	105.00	75.89b
Mean all fertile		45.88	71.31	89.69	107.38	78.50a
Mean all sterile		46.69	67.63	92.13	109.00	79.00a
Overall mean		46.28d	69.47c	90.91b	108.19a	

[a]Means followed by the same letters are not statistically significant ($P = .05$). Letters are applied to means for the main effects of hybrid, cytoplasm and density and for cytoplasm within density and hybrid.

different in stand count at harvest.

The hybrid by density interaction showed that the two tolerant hybrids maintained greater stands at high plant density levels than did the two more intolerant hybrids containing Wf9 similar to the results obtained in 1978.

Tables 14 and 15 show the stand counts as percentages of the expected stands for 1978 and 1979, respectively.

Table 14. Mean stand count at harvest for four hybrids and three plant densities as percentage of expected stand (1978)

Variable	Mean stand count	Stand expected	%
Hybrid			
Wf9 x B37	137.21	140.25	97.83
B37 x B73	141.96	140.25	101.22
A554 x W182	134.50	140.25	95.90
Mo17 x B73	140.67	140.25	100.30
Plant density (plants/ha)			
34,594	88.84	89.25	99.54
54,362	142.50	140.25	101.60
74,130	184.41	191.25	96.42

Table 15. Mean stand count at harvest for four hybrid and four plant densities as percentage of expected stand (1979)

Variable	Mean stand count	Stand expected	%
Hybrid			
Wf9 x B37	77.53	82.25	94.26
B37 x B73	81.69	82.25	99.32
B73 x N28	79.81	82.25	97.03
Wf9 x C103	75.97	82.25	92.36
Plant density (plants/ha)			
39,536	46.28	48.00	96.40
59,304	69.47	70.00	99.25
79,072	90.91	94.00	96.71
98,840	108.34	117.00	92.59

The Fertile Cytoplasm and Date of Pollen Shedding in 1979

Data about the fertile cytoplasm with regard to days to 75% pollen shed in 1979 showed that number of days to pollen shed was significantly affected by hybrid and plant density (Table 16). Wf9 x B73 reached 75% pollen shed 2, 2.7 and 3.7 days earlier than B37 x B73, Wf9 x C103 and B73 x N28, respectively. B37 x B73 also differed significantly from B73 x N28 but not from Wf9 x C102. B73 x N28 and Wf9 x C103 did not

Table 16. Mean squares for days to 75% pollen shed in fertile cytoplasm of four hybrids at four plant densities

Source	df	MS
Rep (R)	3	2.07
Hybrid (H)	3	39.16**
Error a	9	1.88
Density (D)	3	15.56**
H x D	9	0.84
Error b	36	0.78

**Significant at the P = .01 level.

differ (Table 17). A plant density of 39,536 plants/ha resulted in significant earlier attainment of 75% pollen shed by 1.98 and 2.05 days than those of 79,072 and 98,840 plants/ha. The 39,536 plants/ha density level did not differ from the 59,304 plants/ha density. Plant densities of 79,072 and 98,840 plants/ha with 74.68 and 74.80 days did not differ in their effects on days to 75% pollen shed. No significant interactions were observed.

Comparison of Fertile, Cms and Tms Cytoplasms for the 1979 Experiment

The hybrid Wf9 x C103 was the only hybrid that had three different types of cytoplasms: fertile (normal), Cms and Tms. Therefore, an additional separate analysis of variance was done involving only Wf9 x C103 and the three cytoplasms as

Table 17. Mean number of days to 75% pollen shed for four hybrids and four plant densities, 1979

	Plant density (plants/ha)				
Hybrid	39,536	59,304	79,072	98,840	Mean
Wf9 x B37	70.75	71.50	72.00	73.00	71.81c
B37 x B73	72.50	73.75	75.00	74.25	73.88b
B73 x N28	74.50	75.25	76.25	76.00	76.50a
Wf9 x C103	73.25	73.50	75.50	75.98	74.56ab
Mean	72.75b	73.50b	74.69a	74.81a	

shown in Table 18.

For grain yield, there was a significant difference (1% level) in yield due to cytoplasm differences. The fertile cytoplasm gave much less yield than Cms or Tms. The differences were 20.41 q/ha for Cms and 23.01 q/ha for Tms. There was no significant yield difference between Cms and Tms as shown in Table 19.

There was also a significant effect of plant density as well as a cytoplasm by density interaction. The yields for the various plant densities across all cytoplasms were 75.28, 91.39, 100.63, and 101.54 q/ha for 98,840, 79,072, 59,304, and 39,536 plants/ha, respectively. The yields of the different plant densities except between 39,536 and 59,304 plants/ha varied significantly.

In the interaction, yield of cytoplasm was affected by

Table 18. Mean squares for days to 75% silking, barrenness, stand count at harvest and grain yield of three cytoplasms and four plant densities

Source	df	75% silking	Barrenness	Stand count	Grain yield
Rep (R)	3	2.72	41.25	60.91	8.17
Cytoplasm (C)	2	10.20*	927.39**	48.27**	471.57**
Error a	6	1.84	42.19	25.43	11.02
Density (D)	3	23.71**	3342.75**	7864.58**	356.09**
C x D	6	5.86**	355.29**	17.60	34.37**
Error b	27	1.26	25.96	35.35	8.29

*Significant difference at P = .05.

**Significant difference at P = .01

Table 19. Grain yield (q/ha) of three cytoplasms of Wf9 x C103 at four plant densities[a]

	Plant density (plants/ha)				
Cytoplasm	39,536	59,304	79,072	98,840	Mean
Fertile	90.86c	93.77b	75.75b	51.58b	77.74b
Cms	103.20b	102.12a	98.36a	88.90a	98.15a
Tms	110.55a	106.00a	101.08a	85.35a	100.75a
Mean	101.54a	100.63a	91.39b	75.28c	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effects of cytoplasms and plant density, and for cytoplasm within a density.

density. A greater yield difference between cytoplasm occurred with increase in density, especially the difference between sterile and fertile cytoplasms. The difference between the fertile and Cms increased from 12.34 q/ha at 39,536 plants/ha to 37.3 q/ha at 98,840 plants/ha. There was a corresponding increase in differences from 19.7 to 33.8 q/ha between the fertile and Tms cytoplasm. Days to 75% silking, barrenness and stand count at harvest statistical results are shown in Table 18.

Number of days to 75% silking varied significantly at the 5% level between the fertile and the sterile cytoplasms. There was no significant difference between the Cms and Tms cytoplasms. The fertile plants with a mean of 77.14 days to silking were 1.2 and 1.52 days later than Tms and Cms, respectively (Table 20).

The two lower densities did not vary in their effects on days to silking, but were significantly different from the two higher densities which also did not vary between themselves (Table 20). The average difference was 2.2 days earlier silking for the two lower plant densities.

The interaction effect of cytoplasm and density which was significant at the 1% level showed that increasing plant density increased the difference in days to 75% silking between fertile and sterile cytoplasm with the sterile being ahead in silking time.

Percentage barrenness was significantly higher for the

Table 20. Mean number of days to 75% silking for three cytoplasms at four plant densities (1979)[a]

	Plant density (plants/ha)				
Cytoplasm	39,536	59,304	79,072	98,840	Mean
Fertile	74.50a	75.25a	78.75a	80.05a	77.14a
Cms	74.50a	76.00a	76.00b	76.00c	76.63b
Tms	74.50a	76.00a	76.25b	77.00b	75.94b
Mean	74.50b	75.75b	77.00a	77.68a	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effects of cytoplasms and plant density, and for cytoplasm within a density.

fertile (23.77%) than for either the Cms (8.05%) or Tms (12.77%) as shown in Table 21. The Cms and Tms were not significantly different.

The main effect of plant density showed differences in barrenness among density levels. Densities 39,536 and 59,304 plants/ha were not different, but the other densities were different with respect to barrenness. The percentages of barrenness were 0.90%, 4.55%, 18.80%, and 35.2% for 39,536, 59,304, 79,072 and 98,840 plants/ha, respectively.

The interaction between cytoplasm and density was highly significant and showed increasing differences between the fertile and sterile cytoplasms as density was increased. Percentage barrenness increased from 1.9% at 39,536 plants/ha

Table 21. Percent barrenness of three cytoplasms at four plant densities (1979)[a]

Cytoplasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
Fertile	1.67a	6.93a	28.45a	58.04a	23.77a
Cms	0.00a	0.79a	11.65c	19.76c	8.05b
Tms	1.03a	5.94a	16.30b	27.79b	12.77b
Mean	0.90c	4.55c	18.80b	35.20a	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effects of cytoplasms and plant density, and for cytoplasm within a density.

to 58.04% at 98,840 plants/ha for the fertile cytoplasm compared to from 0% to 19.76% for Cms and 1.03% to 27.79% for Tms (Table 21).

By design, the plant densities were different and as expected stand count at harvest was significantly affected by plant densities (Table 22).

There were no significant differences among cytoplasm types in stand count at harvest. There was no interaction between cytoplasm and density either.

Table 22. Mean stand count at harvest for three cytoplasms at four plant densities (1979)[a]

	Plant density (plants/ha)				
Cytoplasm	39,536	59,304	79,072	98,840	Mean
Fertile	45.00a	58.00a	87.00a	104.50a	76.13a
Cms	45.00a	63.25a	88.00a	106.25a	75.63a
Tms	48.50a	71.50a	90.50a	105.25a	78.93a
Mean	46.17d	67.58c	88.50b	105.33a	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effects of cytoplasms and plant density, and for cytoplasm within a density.

Growth of Plant Parts

Due to the fact that the dry weight measurements appeared to be more meaningful than fresh weight or length measurements, dry weight measurements are used in the experiment as the major means of comparison. Also, because the area of most interest relates to the combined or interacting effects of hybrid cytoplasm and density, detailed presentation and discussions of results may be limited to hybrid by density, cytoplasm by density and hybrid by cytoplasm interactions and their relationships in the growth of certain parts.

Sampling of parts was done from 23 July to 17 August 1979, in four short time periods. The midpoint in time of individual periods were: Period 1, 25 July; Period 2, 1 August;

Period 3, 7 August; and Period 4, 15 August.

The average date of 75% silking at low plant density for B73 x N28 was 3 August 1979 and for Wf9 x C103 it was 4 August.

Ear dry weight

According to the statistical analysis in Table 23, the top ear dry weight was significantly affected by plant density during each of the four periods of measurements, all at the 1% level of probability. Neither hybrid nor cytoplasm had a significant effect on ear dry weight at these times. However, there were 5% significant hybrid by density interactions in Periods 3 and 4.

Top ear dry weight was greater for the lower plant density in each period as presented in Table 24. In Period 1, ear weights ranged from 0.22 for the highest density to 1.06 g for the lowest density; in Period 2, from 1.27 to 6.0 g; in Period 3, from 8.68 to 31.75; and for Period 4, from 19.07 to 81.40 g.

The interaction effects of hybrid and density in Periods 3 and 4 are shown in Figure 8. In Period 3, B73 x N28 ear weight was reduced only by 13.92 g by increasing density from 39,536 plants to 98,840 plants/ha, compared to a reduction of 23.07 g for Wf9 x C103 at the same densities. In Period 4, the magnitudes of the reduction were 25.7 g for B73 x N28 and 62.33 g for Wf9 x C103. In each of the periods, Wf9 x C103, which had the greater ear dry weight at lowest density,

Table 23. Mean squares for ear dry weight (EDW), tassel dry weight (TDW), Brix reading (Brix), Node lengths (NodL) and node dry weight (Nod DW) for two hybrids with two cytoplasms at four plant densities during four different periods

Source	df	EDW	TDW	Brix (+)
		Period 1, 1979		
Reps (R)	2	1.0096	6.9621	-
Hybrid (H)	1	0.0001	133.5701**	-
Error a	2	0.0378	0.8704	-
Cytoplasm (C)	1	0.0370	33.6491**	-
H x C	1	0.1269	4.9962	-
Error b	4	0.0455	1.1172	-
Density (D)	3	1.7503**	14.7625**	-
H x D	3	0.0174	4.2851**	-
C x D	3	0.0171	0.5109	-
H x C x D	3	0.0341	0.6241	-
Error c	24	0.1214	0.5743	-
		Period 2, 1979		
Reps (R)	2	6.4133	2.0810	1.3916
Hybrid (H)	1	0.0618	397.5343**	0.4801
Error a	2	0.2680	2.3107	0.0151
Cytoplasm (C)	1	3.0952	265.5392**	0.1267
H x C	1	1.1138	63.0385**	0.2351
Error b	4	0.9147	1.4857	0.1548
Density (D)	3	59.5390**	37.8225**	0.3065*
H x D	3	0.4628	4.4806**	0.0717
C x D	3	1.5726	4.3105*	0.0953
H x C x D	3	0.5248	1.1763	0.0795
Error c	24	1.3723	0.9465	0.08264

*Significant difference at P = .05.

**Significant difference at P = .01.

Brix (-)	NodL 2	NodL-2	+2 Nod DW	-2 Nod DW
1.0272	55.7964	37.7861	-	8.14
0.1255	0.6179	12.1293	-	0.002
0.4140	5.6480	9.1321	-	0.4205
0.2206	18.7450	19.1534	-	1.1102
0.6524	8.2884	0.9433	-	2.0049*
0.2510	6.9915	4.5867	-	0.4124
0.0613	21.1498*	5.9319	-	15.9012**
0.0554	1.6126	2.7197	-	1.2308
0.0238	3.4158	17.7938*	-	1.4384
0.0674	2.1593	1.2955	-	0.6911
0.1221	4.5583	5.9292	-	0.7115
0.4438	24.0989	37.7861	0.9505	1.77
1.4857	5.2516	12.1293	0.7809	0.0001
0.2881	3.2170	9.1320	0.8629	0.299
0.0084	5.1861	19.1534	0.0030	1.073*
0.4198	0.0057	0.9433	0.1145	0.379
0.1109	1.9004	4.5867	0.1785	0.059
1.6123**	34.5624**	5.9319	6.5979**	26.520**
0.3678	5.1381	2.7196	0.1782	0.343
0.4924*	24.5651**	17.7938*	1.0358*	0.921
0.0925	7.0004	1.2954	0.0810	0.354
0.1662	4.1808	5.9292	0.3249	0.392

Table 23. (Continued)

Source	df	EDW	TDW	Brix (+)
		Period 3, 1979		
Reps (R)	2	220.8668	2.1409	4.7957
Hybrid (H)	1	70.7754	188.0617	8.7980
Error a	2	27.9802	1.5976	1.8094
Cytoplasm (C)	1	177.9252	21.7877*	0.0856
H x C	1	86.8000	0.0105	0.0501
Error b	4	42.9168	2.9967	0.5073
Density (D)	3	813.0304**	13.6526**	4.7426**
H x D	3	43.1225*	0.1725	0.2358
C x D	3	7.3828	0.5223	0.2103
H x C x D	3	2.6112	2.0745*	0.0771
Error c	24	14.6607	0.4928	0.4670
		Period 4, 1979		
Reps (R)	1	795.3401	0.0077	0.1292
Hybrid (H)	1	1323.1225	124.8068*	0.4125
Error a	1	78.7513	0.2683	0.6709
Cytoplasm (C)	1	53.3889	0.0837	0.6142
H x C	1	0.5339	0.7412*	0.2278
Error b	2	11.3983	0.0116	0.4904
Density (D)	3	3089.2330**	13.3696**	0.4631
H x D	3	514.9481*	1.2671	0.2453
C x D	3	176.0589	0.0635	0.5121
H x C x D	3	209.0368	0.2045	0.2644
Error c	24	153.2859	0.8195	0.2665

Brix (-)	NodL 2	NodL-2	+2 Nod DW	-2 Nod DW
1.7359	1.1362	0.0813	0.0711	0.7308
19.7061*	11.6201*	24.4317*	0.0194	0.4901
1.1913	0.2965	1.3508	0.2020	0.5005
0.0278	2.4829*	1.6215*	0.3913	1.6398
0.0294	0.0662	0.0278	0.0722	0.5036
0.1800	0.1182	0.1750	0.4537	1.2349
1.8172**	2.5335*	10.4266**	9.0818**	48.4000**
0.3643	3.2464**	2.5977	0.0573	0.2101
0.1124	1.4550	0.5721	0.0419	0.5535
0.0312	0.0346	1.0942	0.0719	0.3930
0.3769	0.6618	1.5237	0.2951	1.2471
2.2050	1.8368	1.7113	0.3167	0.6281
1.8689	0.3068	14.7606	0.3865	0.0994
1.6806	0.0356	2.2050	0.0438	0.0994
0.0235	0.7200	0.2222	0.1582	0.4552
0.2813	5.7234*	0.0001	0.0390	0.0000
1.0307	0.0662	3.2581	0.0073	0.9017
0.8978	5.0078**	6.3978*	11.1864**	62.4469**
0.0880	5.3285**	2.1275	0.3792	0.9274
0.2974	0.8465	0.8545	0.0227	0.1683
0.1274	0.1758	0.7046	0.4660	2.0493
0.2946	0.7026	1.0914	0.4167	2.4123

Table 24. Mean ear dry weight of two hybrids with two cytoplasms for four plant densities at four different periods (1979)[a]

Hybrid	Cytoplasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
			Period 1			
B73 x N28	F	1.17a	0.50a	0.25a	0.39a	0.58
	S	0.90a	0.40a	0.28a	0.14a	0.43
	Mean	1.04	0.45	0.27	0.27	0.51a
Wf9 x C103	F	0.97a	0.45a	0.30a	0.15a	0.47
	S	1.18a	0.35a	0.36a	0.17a	0.52
	Mean	1.08	0.40	0.33	0.16	0.49a
Mean of Fs		1.07	0.48	0.28	0.27	0.53a
Mean of Ss		1.04	0.38	0.32	0.16	0.48a
Overall mean		1.06a	0.43b	0.30b	0.22b	
			Period 2			
B73 x N28	F	4.87b	3.47a	1.32a	1.03	2.67
	S	6.75a	4.36a	1.95a	0.88	3.49
	Mean	5.81	3.92	1.64	0.96	3.08a
Wf9 x C103F	F	5.36a	3.72a	1.43a	1.11a	2.91
	S	6.64a	3.03a	1.34a	1.42a	3.11
	Mean	6.00	3.38	1.39	1.27	3.01a
Mean of Fs		5.12	3.60	1.38	1.07	2.79a
Mean of Ss		6.70	3.70	3.70	1.15	3.81a
Overall mean		5.91a	3.65b	2.55bc	1.11c	
			Period 3			
B73 x N28	F	22.99a	16.97a	11.17a	9.73a	15.22
	S	25.36a	18.18a	11.18a	10.79a	16.38
	Mean	24.18	17.58	11.18	10.26	15.80a
Wf9 x C103F	F	27.59b	16.99a	11.02a	4.26b	14.95
	S	35.90a	22.00a	14.99a	13.10a	43.00
	Mean	31.75	19.47	13.01	8.68	28.98a
Mean						
Mean of Fs		25.29	16.96	11.10	7.00	15.09a
Mean of Ss		30.63	20.09	13.09	11.95	18.94a
Overall mean		27.96a	18.53a	12.10bc	9.48c	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effect of hybrid, cytoplasm and density, and for cytoplasm within a density and hybrid.

Table 24. (Continued)

Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 4				
B73 x N28	F	48.98a	26.02a	24.52a	19.14a	29.67
	S	44.66a	37.94a	22.27a	23.09a	31.99
	Mean	46.82	31.98	23.40	21.12	30.83a
WF9 x C103	F	88.01a	52.62a	20.92a	7.52b	42.27
	S	74.78a	40.76a	34.28a	30.61a	45.11
	Mean	81.40	46.69	27.60	19.07	43.69a
Mean of Fs		68.50	39.32	22.72	13.33	35.97a
Mean of Ss		59.72	39.35	28.28	26.85	38.55a
Overall mean		64.11a	39.34b	25.50bc	20.09c	

had the lesser weight at the highest density.

Figure 9 presents ear dry weight of fertile and sterile cytoplasms within hybrids at the different periods. With Wf9 x C103 there was little difference in ear weight of the two cytoplasm types at the lowest plant density; actually, at Period 4, the fertile appeared to have larger ears than the sterile. At the highest stand density, ear weight of the fertile was significantly less than that of the sterile after Period 2.

For B73 x N28, the more population tolerant hybrid, there appeared to be little effect of cytoplasm on ear weight. Although not compared statistically, it is interesting to note that the rate of growth of the ear of Wf9 x C103 between Periods 3 and 4 at the two lower stand densities is appre-

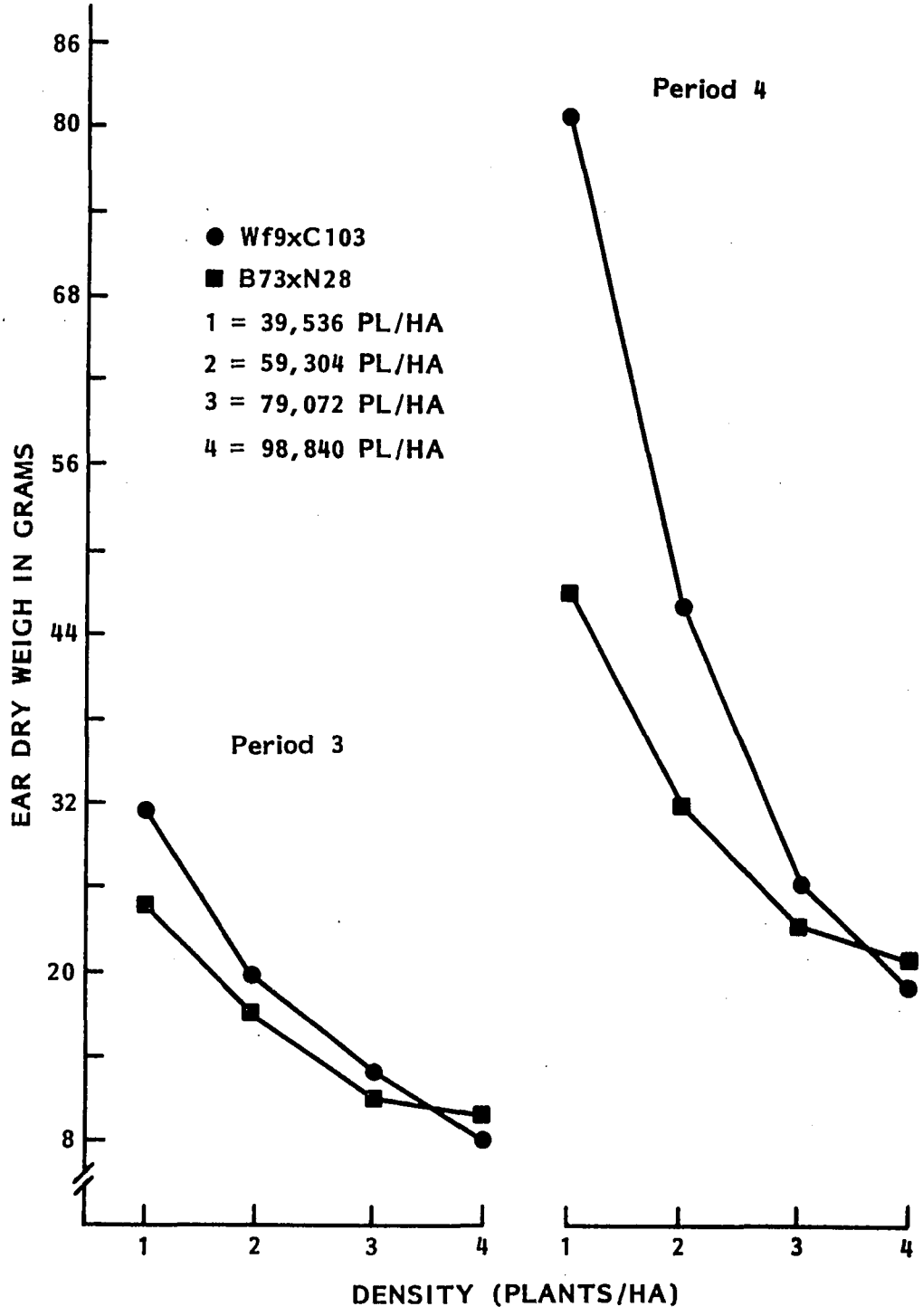


Figure 8. The ear dry weight of two hybrids as affected by plant densities during Periods 3 and 4 (1979)

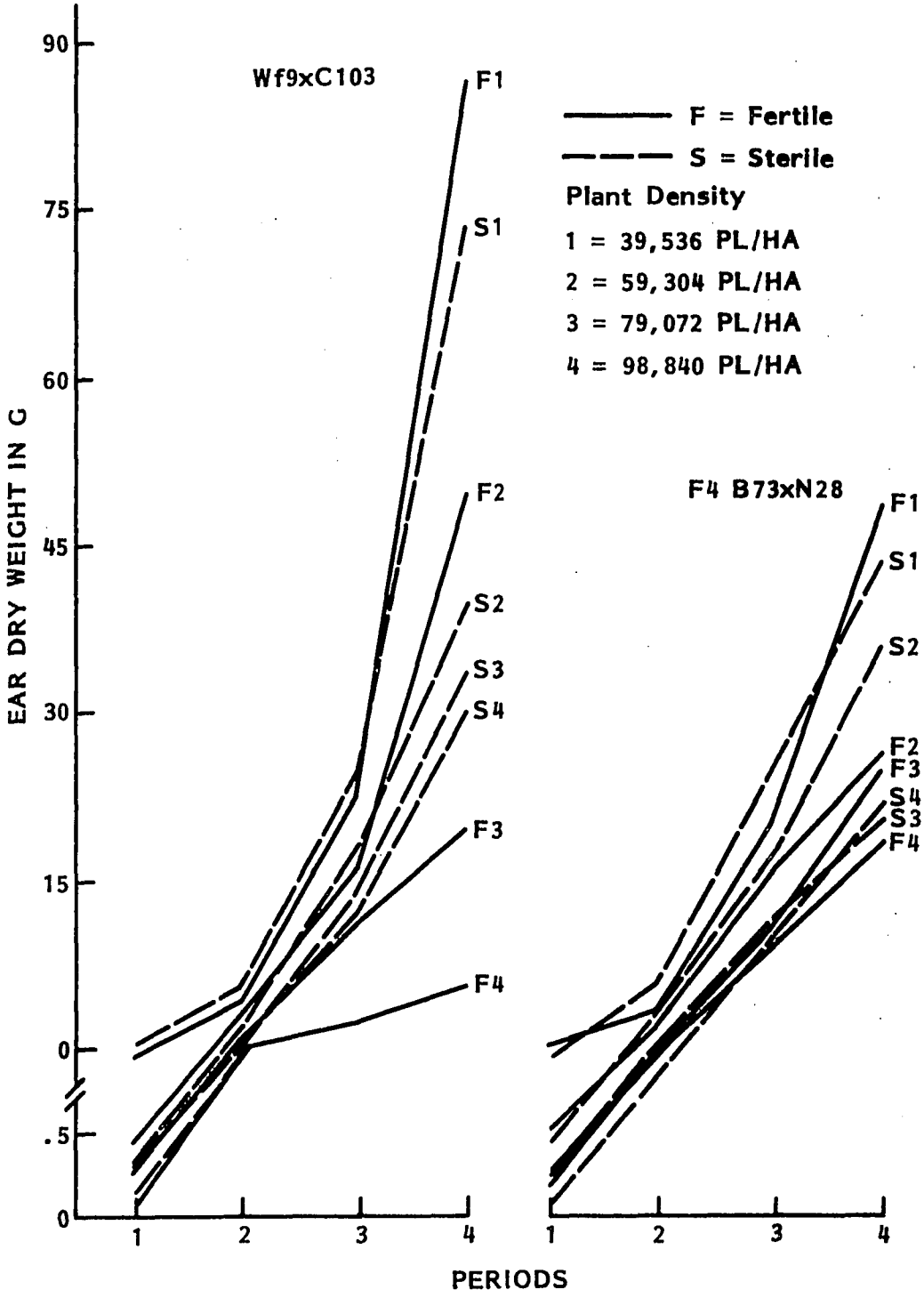


Figure 9. Ear dry weight of fertile and sterile cytoplasms, in two hybrids as affected by plant densities at various periods (1979)

ciably greater than ear growth rate for B73 x N28.

Tassel dry weight

Tassel dry weight varied significantly at 1% and 5% levels for hybrid and density, in all the periods, but varied with cytoplasm in Periods 1, 2, and 3 only. The hybrid x density interaction was significant at the 5% level in Period 1 and at the 1% level in Period 2, but not significant in Periods 3 and 4. The cytoplasm x density and hybrid x cytoplasm interactions were significant at Period 2 only (Table 23).

Wf9 x C103 in all periods consistently had a greater tassel dry weight across densities and cytoplasms than did B73 x N28 (Table 25). Weight differences were 3.33, 5.75, 3.98, and 3.95 g for Periods 1, 2, 3, and 4, respectively. Differences for Periods 1, 2, and 3 were significant at the 1% level. The difference at Period 4 was significant at the 5% level.

At all periods, the lowest density resulted in the greatest dry weight per tassel and the highest resulted in the least weight. The fertile cytoplasm had significantly greater tassel weights than the sterile at the first three periods, but was not significantly greater at Period 4.

The hybrid by density interaction showed that the two hybrids responded differently to increases in plant density at Period 2. B73 x N28 was affected less by density pressure

Table 25. Mean tassel dry weight of two hybrids with two cytoplasms for four plant densities at four different periods (1979)[a]

Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 1				
B73 x N28	F	3.47a	1.85a	1.29a	2.43a	2.26
	S	1.83b	1.39a	0.90a	0.79a	1.23
	Mean	2.65	1.62	1.10	1.61	1.75b
Wf9 x C103	F	8.62a	6.74a	5.36a	4.23a	6.24
	S	5.86b	3.99b	3.37b	2.46b	3.92
	Mean	7.24	5.37	4.35	3.35	5.08a
Mean of Fs		6.05	4.30	3.33	3.33	4.25a
Mean of Ss		3.85	2.69	2.14	1.63	2.57b
Overall mean		4.95a	3.50b	2.73b	2.48b	
		Period 2				
B73 x N28	F	5.53a	5.37a	2.90a	2.79a	4.14
	S	2.78b	2.07b	1.13b	0.84b	1.71
	Mean	4.16	3.72	2.02	1.79	2.93b
Wf9 x C103	F	16.10a	13.53a	9.72a	9.31a	12.17
	S	7.02b	5.76b	4.43b	3.54b	5.19
	Mean	11.56	9.65	7.08	6.43	8.68a
Mean of Fs		10.81	9.45	6.31	6.03	8.15a
Mean of Ss		4.90	3.92	2.78	2.19	3.45b
Overall mean		7.86a	6.69a	4.55b	2.23c	
		Period 3				
B73 x N28	F	5.09a	3.38a	2.58a	2.11a	3.29
	S	2.97b	2.20a	1.49a	1.34a	2.00
	Mean	4.03	2.79	2.04	1.73	2.65b
Wf9 x C103	F	8.20a	7.18a	6.70a	7.74a	7.31
	S	8.00a	6.68a	4.58b	4.48b	5.94
	Mean	8.10	6.93	5.64	5.76	6.63a
Mean of Fs		6.65	5.28	4.64	4.63	5.30a
Mean of Ss		5.49	4.44	3.04	2.91	3.97b
Overall mean		6.07a	4.86b	3.84b	3.77b	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effect of hybrid, cytoplasm and density, and for cytoplasm within a density and hybrid.

Table 25. (Continued)

Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 4				
B73 x N28	F	3.93a	2.29a	1.71a	1.63a	2.39
	S	3.10a	2.17a	1.48a	1.19a	1.99
	Mean	3.52	2.23	1.60	1.41	2.19b
Wf9 x C103	F	7.94a	6.53a	5.69a	3.98a	6.04
	S	8.38a	5.73a	5.32a	4.53a	6.24
	Mean	8.16	6.63	5.51	4.26	6.14a
Mean of Fs		5.94	4.41	3.70	2.81	4.22a
Mean of Ss		5.74	4.45	3.45	2.86	4.13a
Overall means		5.84a	4.43b	3.58bc	2.84c	

than was Wf9 x C103.

The cytoplasm by density interaction which was significant at the 5% level in Period 2 showed that tassel weight of fertile plants decreased more with an increase in plant density than did tassels of sterile plants.

The significant interaction of hybrid and cytoplasm in Period 2 appears to be due to a greater difference in tassel weight between the fertile and sterile of Wf9 x C103 than for B73 x N28.

A representation of tassel dry weight of fertile and sterile cytoplasms of hybrids at different densities and at different periods is given in Figure 10.

The graph for Wf9 x C103 and B37 x N28 both show that smaller tassel dry weights were obtained at each period, when

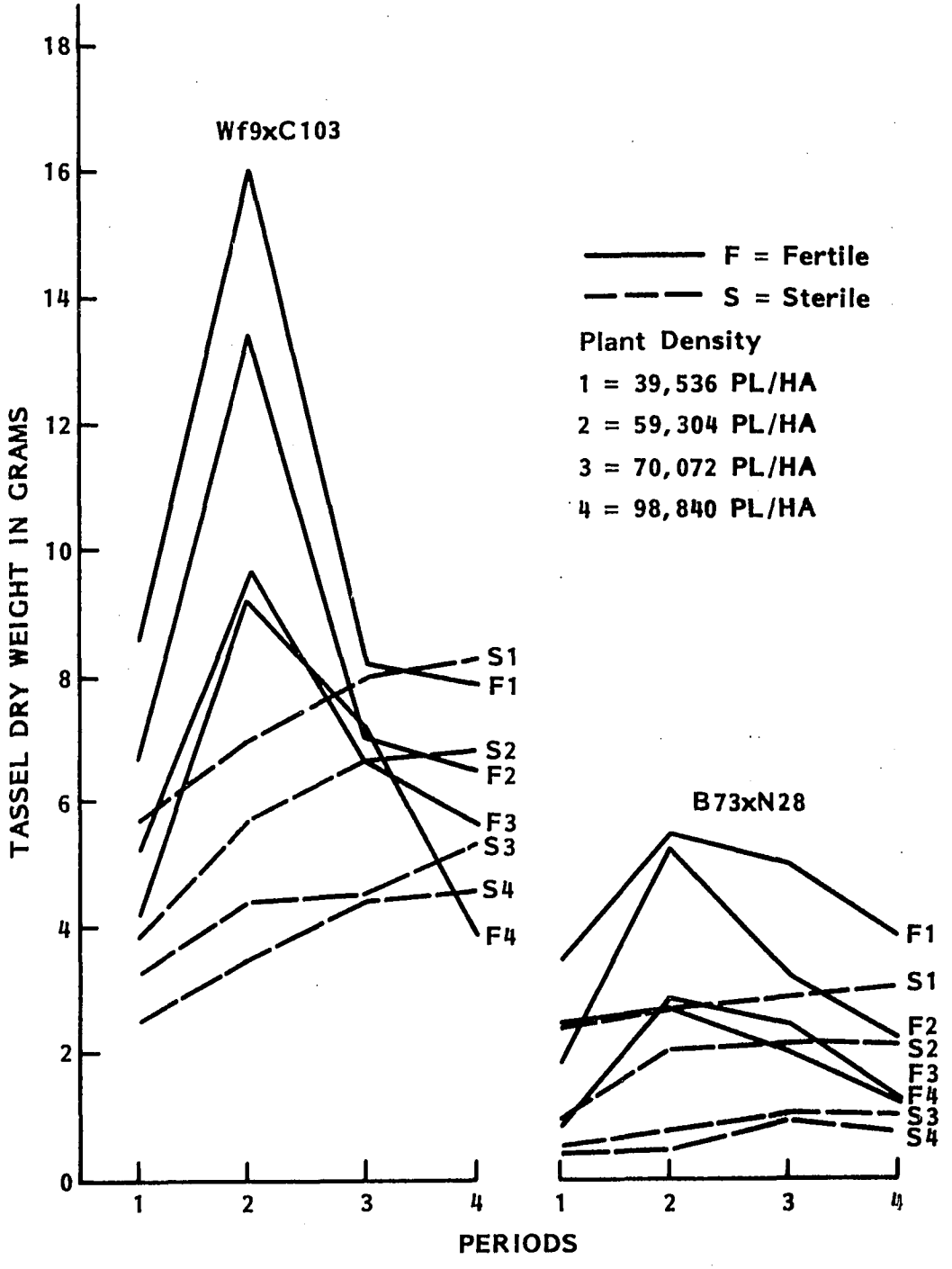


Figure 10. Tassel dry weight of sterile and fertile cytoplasms in two hybrids as affected by plant densities at various periods (1979)

densities were increased. Tassel dry weights for the fertile cytoplasm increased sharply in Period 2 and dropped sharply thereafter as pollen was shed. The increase of the sterile cytoplasms in both hybrids were more gradual.

Tassel dry weight for the fertile cytoplasm of Wf9 x C103 was greater at every density than for the sterile in Periods 1, 2, and 3. However, by Period 4, the dry weights were similar. All differences within hybrids at different densities are as shown by Duncan's multiple range test in Table 25.

In B73 x N28, tassel dry weight for the fertile cytoplasm was consistently greater than the sterile at each period and for every plant density. The difference in tassel size for the two hybrids is apparent in Figure 10. The population intolerant hybrid, Wf9 x C103, had a much larger tassel and a greater production of pollen as indicated by the decrease in dry weights between Periods 2 and 4.

Internodes

Internode development (second above or below the node of first ear attachment) at all four periods was significantly affected by plant density (Table 23).

The upper internode weight varied with density at the 1% level of significance at Periods 2, 3, and 4. No measurements were obtained for Period 1. No other significant main effects were observed at any period. There was, however, a 5%

significant interaction effect of cytoplasm and density in Period 2.

Dry weight per internode was reduced from 2.79 g at 39,536 plants/ha to 1.27 g at 98,840 plants/ha in Period 2. Corresponding reductions were from 4.23 to 2.33 g for Period 3, and from 5.26 to 2.62 g in Period 4 as shown in Table 26.

The interaction of cytoplasm and density in Period 2 showed that the internodes of sterile plants had larger decreases in growth than did the fertile as plant density increased. This response of the internodes in plant density and cytoplasm was the opposite of the response of the ear.

The lower internode weight, like the upper internode, was affected significantly (1% level) at all periods by plant density. Effect due to cytoplasm was significant at the 5% level in Period 2. Hybrid did not show any significant effect on lower internode dry weight at any period, and there were no significant interactions (Table 23).

Again, increasing plant density decreased the internode dry weight during each period, as shown in Table 27. The 5% significant effect of cytoplasm shows that the sterile cytoplasm had a higher internode weight than the fertile by 0.31 g when averaged across plant densities.

Although the density by cytoplasm interaction was not significant, the growth of the lower internode of the sterile decreased more than did those of the fertile as plant density increased. This effect of cytoplasm becomes progressively

Table 26. Mean dry weight of second internode above the ear of two hybrids with two cytoplasms for four plant densities at three different periods (1979)[a]

Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 2				
B73 x N28	F	2.62a	2.62a	1.26a	1.42a	1.98
	S	3.30a	2.31a	1.59a	1.05a	2.06
	Mean	2.96	2.46	1.42	1.23	2.02a
Wf9 x C103	F	2.27a	2.43a	1.14a	1.45a	1.82
	S	2.99a	1.48b	1.21a	1.17a	1.71
	Mean	2.63	1.95	1.17	1.31	1.76a
Mean of Fs		2.44	2.52	1.20	1.43	1.90a
Mean of Ss		3.14	1.84	1.40	1.11	1.88a
Overall mean		2.79a	2.21a	1.30b	1.27b	
		Period 3				
B73 x N28	F	4.16a	3.24a	2.35a	2.53a	3.07
	S	4.38a	3.23a	2.70a	2.39a	3.17
	Mean	4.27	3.235	2.52	2.46	3.12a
Wf9 x C103	F	4.00a	3.10a	2.43a	2.10a	2.91
	S	4.39a	3.49a	2.50	2.28a	3.16
	Mean	4.19	3.29	2.46	2.19	3.04a
Mean of Fs		4.08	3.17	2.39	2.32	2.99a
Mean of Ss		4.385	3.36	2.60	2.33	3.17a
Overall mean		4.23a	3.26b	2.49b	2.33b	
		Period 4				
B73 x N28	F	5.38a	3.23b	2.89a	3.16a	3.66
	S	5.48a	4.13a	3.03a	2.86a	3.87
	Mean	5.42	3.68	2.96	3.01	3.77a
Wf9 x C103	F	5.00a	4.16a	3.00a	1.90a	3.51
	S	5.20a	3.72a	2.84a	2.58a	3.58
	Mean	5.10	3.94	2.92	2.24	3.55a
Mean of Fs		5.19	3.69	2.94	2.53	3.59a
Mean of Ss		5.34	3.92	2.93	2.72	3.73a
Overall mean		5.26a	3.81b	2.94c	2.62c	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effect of hybrid, cytoplasm and density, and for cytoplasm within a density and hybrid.

Table 27. Mean dry weight of second internode below the ear of two hybrids with two cytoplasms for four plant densities at four different periods (1970)[a]

Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 1				
B73 x N28	F	5.11a	3.09a	3.09a	4.17a	3.86
	S	4.48a	3.37a	2.69a	2.07b	3.16
	Mean	4.79	3.23	2.89	3.12	3.51a
Wf9 x C103	F	5.09a	3.39a	2.73a	2.66a	3.47
	S	6.12a	3.41a	2.61a	2.17a	3.58
	Mean	5.60	3.40	2.67	2.41	3.52a
Mean of Fs		5.10	3.24	2.91	3.41	3.66a
Mean of Ss		5.30	3.39	2.65	2.12	3.36b
Overall mean		5.20a	3.31b	2.78b	2.76b	
		Period 2				
B73 x N28	F	6.36b	6.02a	4.32a	4.16a	5.21
	S	7.68a	6.58a	4.83a	3.62a	5.63
	Mean	7.03	6.30	4.57	3.89	5.44a
Wf9 X C103	F	7.03a	6.14	4.16	4.20	5.38
	S	7.83a	5.69a	4.27a	4.28a	5.52
	Mean	7.43	5.91	4.21	4.24	5.45a
Mean of Fs		6.69	6.08	4.24	4.18	5.29b
Mean of Ss		7.75	6.13	4.55	3.95	5.60a
Overall mean		7.22a	6.10a	4.39b	4.06b	
		Period 3				
B73 x N28	F	9.74a	7.15a	5.41a	5.92a	7.06
	S	9.92a	7.37a	6.08a	5.54a	7.23
	Mean	9.83	7.26	5.74	5.73	7.14a
Wf9 x C103	F	9.12a	6.82a	5.43a	5.24a	6.65
	S	10.35a	7.88a	5.54a	5.14a	7.23
	Mean	9.73	7.35	5.48	5.19	6.94a
Mean of Fs		9.43	6.98	5.42	5.58	6.86a
Mean of Ss		10.13	7.62	5.81	5.34	7.23a
Overall mean		9.78a	7.30b	5.61b	5.46b	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effect of hybrid, cytoplasm and density, and for cytoplasm within a density and hybrid.

Table 27. (Continued)

Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 4				
B73 x N28	F	12.38a	7.13a	6.68a	6.78a	8.24
	S	11.77a	9.06a	6.82a	6.28a	6.48
	Mean	12.07	8.09	6.75	6.53	7.36a
Wf9 x C103	F	12.13a	9.16a	6.95a	5.18a	8.35
	S	13.09a	8.43a	6.60a	6.26a	8.59
	Mean	12.61	8.79	6.77	5.72	8.47a
Mean of Fs		12.25	8.14	6.81	5.98	8.29a
Mean of Ss		12.43	8.74	6.71	6.27	7.53a
Overall mean		12.34a	8.44b	6.76bc	6.12c	

less with time of sampling as was also shown by the upper internode.

It may be of interest to note that growths of internodes were continuing at Period 4 in both hybrids.

Another aspect of internode development is internode increase in length; and this also was affected by density of planting (Table 23). The second upper internode varied significantly in length with change in density in every period; at the 5% level for Period 1 and at the 1% level in Periods 2, 3, and 4. Hybrid and cytoplasm effects were both significant at the 5% level in Period 3. There were hybrid by density interactions at the 1% level in Periods 3 and 4, and a hybrid by cytoplasm interaction at the 5% level in Period 4.

In Period 3, Wf9 x C103 had a longer second internode

than B73 x N28. The difference of 0.99 cm was significant at the 5% level (Table 28). Sterile cytoplasm was observed to be longer than the fertile cytoplasm by a 5% significant 0.45 cm at the same period also.

The effects of plant densities varied from period to period. Mean lengths of internode were separated by Duncan's multiple range test as shown in Table 28. The general trend was that the lower density had longer internodes in the earlier periods but the higher density became longer in the later periods. The hybrid by density interactions in Periods 3 and 4 showed that the internodes of B73 x N28 tended to increase with increasing plant density, whereas in Wf9 x C103 there was a slight decrease or no change.

The hybrid by cytoplasm interaction significant at the 5% level of probability in Period 4 was due to the fertile of B73 x N28 being longer than the sterile, whereas the reverse was true for Wf9 x C103.

The elongation of the upper internode occurred mainly during the two-week interval before time of 75% silking (the interval between Periods 1 and 3). Although not statistically significant, the density by cytoplasm interaction for both hybrids at the Period 1 and 2 measurements indicate that as the stress from plant density increased the internodes of sterile plants elongated less than did the fertile internodes.

The second lower internode also varied in length with density at the 1% level of significance in the second and

Table 28. Mean length of second internode above the ear of two hybrids with two cytoplasms for four plant densities at four different periods (1979)[a]

Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 1				
B73 x N28	F	6.28a	3.18a	3.21a	6.26a	4.73
	S	4.53a	2.22a	2.31a	1.53b	2.65
	Mean	5.41	2.70	2.76	3.90	3.69a
Wf9 x C103	F	5.42a	3.38a	2.82	3.07a	3.67
	S	5.92a	2.46a	2.51a	2.13a	3.26
	Mean	5.67	2.92	2.67	2.60	3.47a
Mean of Fs		5.85	3.28	3.02	4.67	4.21a
Mean of Ss		5.23	2.34	2.41	1.83	2.95a
Overall mean		5.54a	2.81ab	2.72b	3.25ab	
		Period 2				
B73 x N28	F	15.32a	16.68a	13.44a	14.61a	15.01
	S	15.92a	16.42a	14.88a	10.29b	14.38
	Mean	15.62	16.55	14.16	12.45	14.70a
Wf9 x C103	F	14.84a	17.51a	10.74a	14.39a	14.37
	S	17.27a	12.64b	13.42a	11.44b	13.69
	Mean	16.06	15.08	12.08	12.92	14.03a
Mean of Fs		15.08	17.10	12.09	14.50	14.69a
Mean of Ss		16.60	14.53	14.15	10.87	14.03a
Overall mean		15.84a	15.82a	13.12ab	12.69b	
		Period 3				
B73 x N28	F	16.88a	18.03a	17.80a	17.72a	17.61
	S	16.79a	17.54a	18.84a	18.78a	17.99
	Mean	16.84	17.79	18.12	18.25	17.80b
Wf9 x C103	F	18.74a	19.22a	18.90a	17.21b	18.52
	S	18.88a	19.12a	19.82a	18.37a	19.05
	Mean	18.81	19.17	19.36	17.79	18.79a
Mean of Fs		17.81	18.63	18.35	17.47	18.07b
Mean of Ss		17.84	18.33	19.33	18.58	18.52a
Overall mean		17.83b	18.48ab	18.84a	18.03ab	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effect of hybrid, cytoplasm and density, and for cytoplasm within a density and hybrid.

Table 28. (Continued)

Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 4				
B73 x N28	F	17.70a	18.15a	19.45a	19.35a	18.66
	S	16.23b	17.63a	19.12a	19.48a	18.12
	Mean	16.97	17.89	19.29	19.37	18.39a
Wf9 x C103	F	17.17a	19.18a	17.90b	16.23b	17.62
	S	17.77a	19.58a	19.80a	17.92a	18.78
	Mean	17.47	19.38	18.85	17.08	18.20a
Mean of Fs		17.44	18.67	18.68	17.79	18.15a
Mean of Ss		17.00	18.61	19.46	18.70	18.44a
Overall mean		17.22c	18.64a	19.07a	18.25ab	

third periods and at the 5% in the fourth period. Internode length also varied at the 5% level with hybrid and cytoplasms in Period 3. There was a significant cytoplasm by density interaction at the 5% level in Period 1, and a hybrid by density interaction significant at the 1% level in Period 2 (Table 23). The lower internodes of Wf9 x C103 was 1.43 cm longer than the comparable internode of B73 x N28 at Period 3 (Table 29). The sterile cytoplasm at Period 3 had internodes 0.34 cm longer than the internodes of the fertile when averaged across densities.

In Periods 2 and 3, the higher stand densities produced longer internodes than the lower densities. Mean internode lengths in Period 2 were 19.23, 20.65, 21.25, and 21.62 cm for 39,536, 59,304, 79,072 and 98,840 plants/ha, respectively.

Table 29. Mean length of second internode below the ear of two hybrids with two cytoplasms for four plant densities at four different periods (1979)[a]

Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 1				
B73 x N28	F	18.08a	15.93a	18.32a	19.48a	17.95
	S	17.49a	17.90a	16.21a	16.28a	16.97
	Mean	17.79	16.92	17.27	17.88	17.46a
Wf9 x C103	F	19.60a	17.78a	18.97a	20.60a	19.24
	S	20.43a	18.58a	15.78a	16.00b	17.70
	Mean	20.02	18.18	17.38	18.30	18.48a
Mean of Fs		18.84	16.86	18.65	20.04	18.60a
Mean of Ss		18.96	18.24	16.00	16.14	17.33a
Overall mean		18.90a	17.55a	17.33a	18.09a	
		Period 2				
B73 x N28	F	18.56a	19.70a	21.08a	22.17a	20.38
	S	18.10a	20.38a	21.22a	22.41a	20.53
	Mean	18.33	20.04	21.15	22.29	20.46a
Wf9 x C103	F	19.74a	21.30a	20.78a	19.10a	20.23
	S	20.51a	21.22a	21.90a	22.77a	21.60
	Mean	20.13	21.26	21.34	20.94	20.92a
Mean of Fs		19.15	20.50	20.93	20.64	20.31a
Mean of Ss		19.31	20.80	21.56	25.59	21.81a
Overall mean		19.23c	20.65b	21.25ab	21.62a	
		Period 3				
B73 x N28	F	18.90a	17.80b	21.11a	21.30a	19.78
	S	18.70a	19.64a	20.71a	21.33a	20.10
	Mean	18.80	18.72	20.96	21.32	19.94b
Wf9 x C103	F	20.71a	20.78a	21.72a	21.41a	21.16
	S	21.24a	20.98a	22.38a	21.69a	21.57
	Mean	20.98	20.88	22.05	21.55	21.37a
Mean of Fs		19.81	19.29	21.42	21.36	20.50a
Mean of Ss		19.97	20.31	21.55	21.51	20.84a
Overall mean		19.89bc	19.80c	21.49a	21.44ab	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effect of hybrid, cytoplasm and density, and for cytoplasm within a density and hybrid.

Table 29. (Continued)

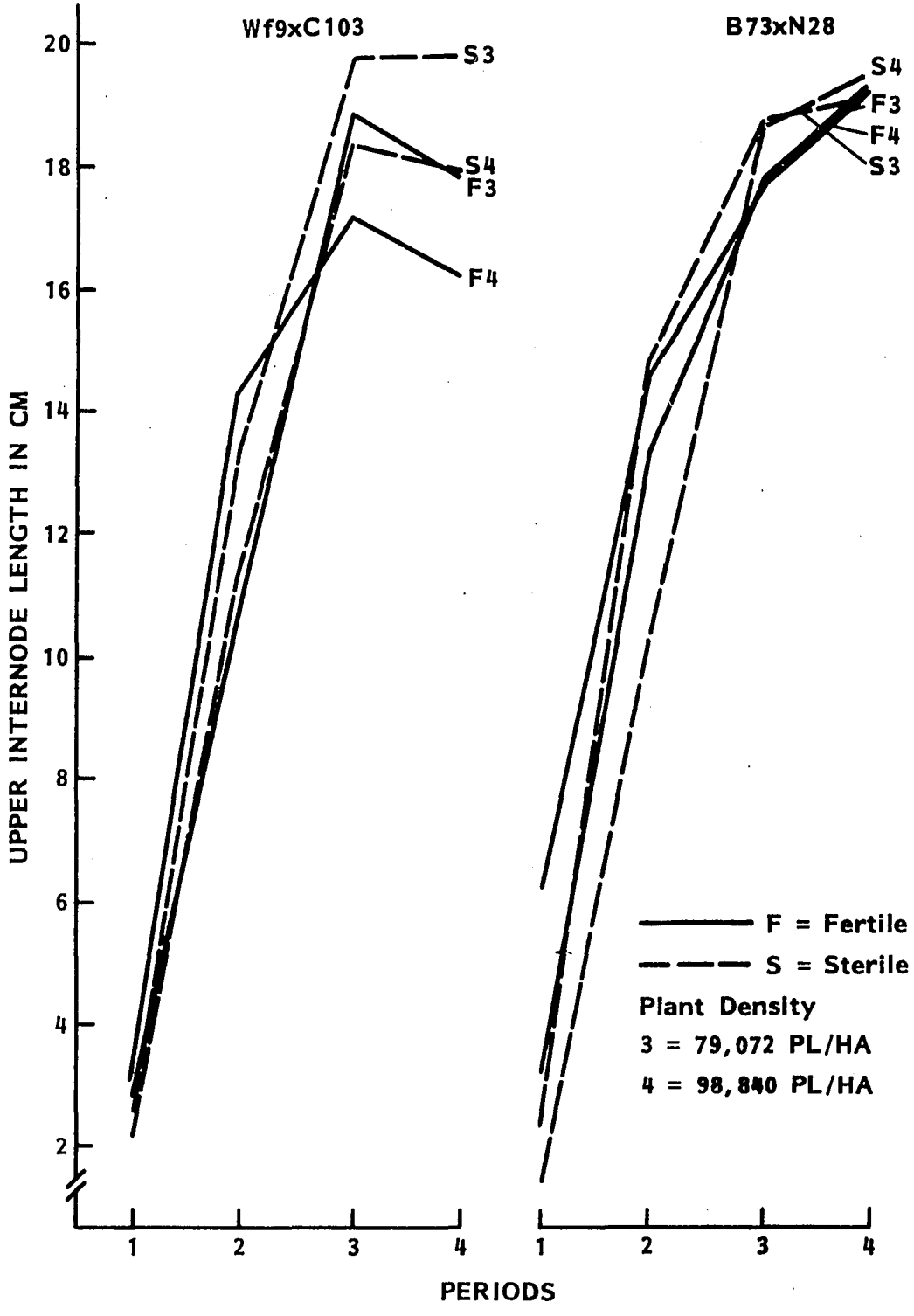
Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 4				
B73 x N28	F	18.52a	19.38a	21.90a	21.93a	20.43
	S	18.77a	21.23a	21.35a	21.00a	20.60
	Mean	18.65	20.31	21.63	21.48	20.52a
Wf9 x C103	F	21.18a	21.88a	22.22a	21.87a	21.79
	S	21.40a	22.08a	22.65a	21.70a	21.96
	Mean	21.29	21.98	22.44	21.79	21.88a
Mean of Fs		19.85	20.63	22.06	21.90	21.11a
Mean of Ss		20.09	21.66	21.79	21.37	21.23a
Overall mean		19.97b	21.15ab	21.93a	21.64ab	

The plant density of 39,536 plants/ha varied significantly from each of the other densities, but the three higher densities did not vary significantly among themselves. In Period 3, the two lower densities did not vary between themselves but varied significantly from the two higher densities which also did not vary between themselves.

The cytoplasm by density interaction in Period 1 was due to an increase of internode length as plant density increased in the plants with a fertile cytoplasm and a decrease in the plants with sterile cytoplasm. The hybrid by density interaction in Period 2 was due to an increase of internode length with increasing density in B73 x N28 and little change in Wf9 x C103.

Figure 11 represents mean lengths of upper internodes of

Figure 11. Mean length of upper internode of fertile and sterile cytoplasms in two hybrids as affected by plant densities at various periods (1979)


Wf9xC103
B73xN28
S3
S4
F3
F4
S4
F3
F4
S3
UPPER INTERNODE LENGTH IN CM
20
18
16
14
12
10
8
6
4
2
1
2
3
4
1
2
3
4
PERIODS
F = Fertile
S = Sterile
Plant Density
3 = 79,072 PL/HA
4 = 98,840 PL/HA

fertile and sterile cytoplasm of two hybrids at four different densities during four different periods. Only effects at 79,072 and 98,840 plants/ha densities are presented.

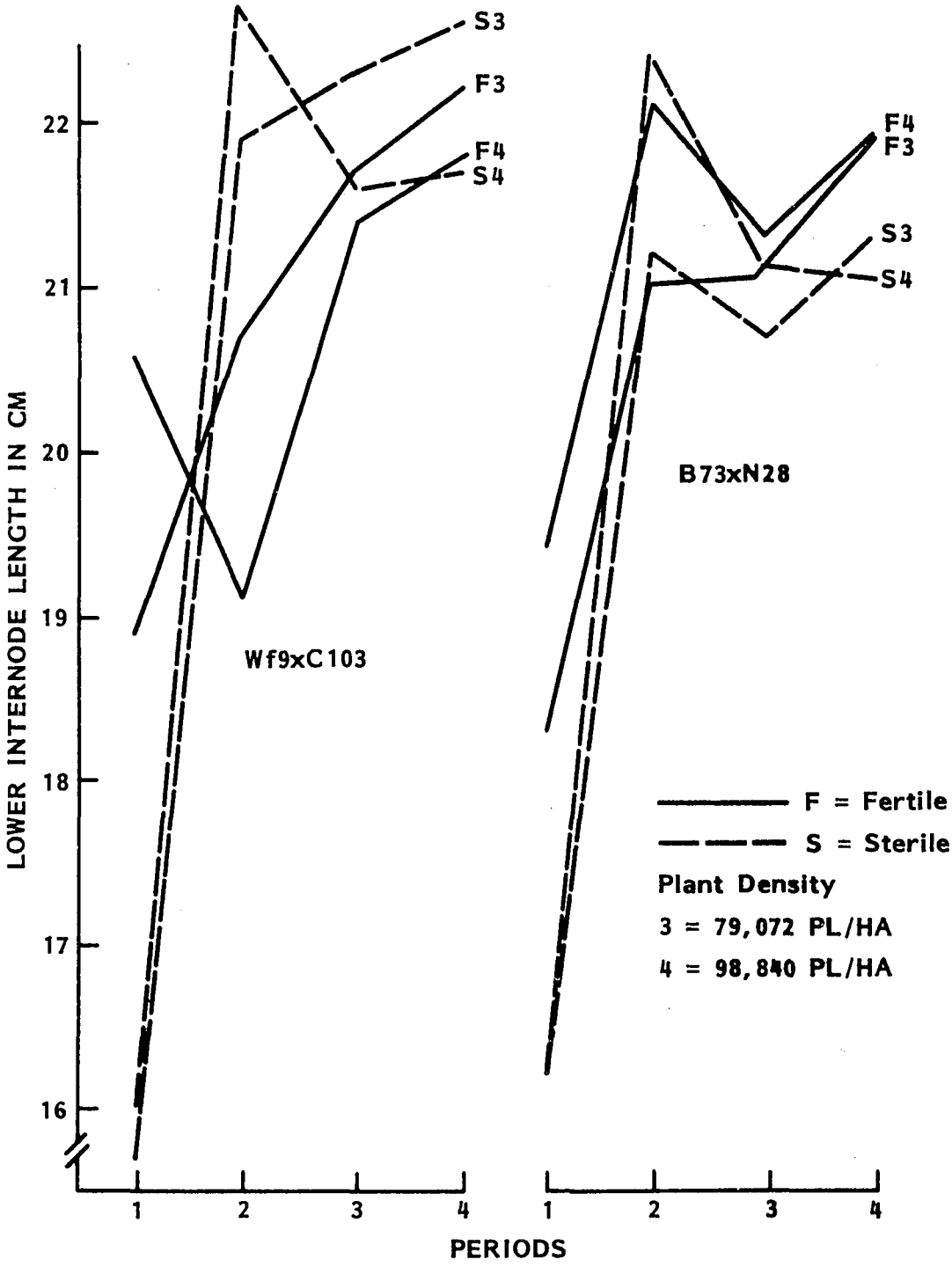
There was a rapid elongation of upper internodes between Periods 1 and 2. At the 79,072 plant density, the plants with sterile cytoplasm tended to be shorter than the fertile but at Periods 2, 3, and 4, no trend was apparent. At a density of 98,840 plants/ha the plants with sterile cytoplasm were frequently significantly shorter than those with fertile cytoplasm at Periods 1 and 2. After pollen shed (Periods 3 and 4) the internodes of the sterile were equally as long or longer than those of the fertile.

The elongation of the second internode below the ear is presented in Figure 12 for hybrids, cytoplasm and densities studied. Again, only the data for the two highest densities are presented. In contrast to the upper internode, the lower internode was nearly fully elongated at Period 1. The only exceptions were the sterile cytoplasm of the two hybrids at the two highest densities at Period 1.

Brix reading

The effect of plant density on Brix reading (Table 23) was significantly different at the 5% level for the upper internode and at the 1% level for the lower internode during Period 2, and significantly different at the 1% level for both the upper and lower internodes during Period 3. In Period 3,

Figure 12. Mean length of lower internode of fertile and sterile cytoplasms in two hybrids as affected by plant densities at various periods (1979)


S3
F3
F4
S4
22
21
20
19
18
17
16
LOWER INTERNODE LENGTH IN CM
Wf9xC103
B73xN28
F4
F3
S3
S4
F = Fertile
S = Sterile
Plant Density
3 = 79,072 PL/HA
4 = 98,840 PL/HA
1
2
3
4
1
2
3
4
PERIODS

Brix reading for the lower internode also varied with hybrid at the 5% level of probability. Apart from the significant differences mentioned above, there were no other significant treatment main effects or interactions for Brix reading. The mean value for the upper internode in Period 2 was greater for the lowest plant density than for the subsequent higher densities, ranging from 5.45% for the lowest density to 4.11% for the highest density as in Table 30, and comparable values for the lower internode were 4.94 to 3.31% (Table 31). In Period 3 the upper internode values varied from 8.16 to 6.64 as density changed from lowest to highest and the comparable values for the lower internode were 7.98 to 6.86%. At periods 1 and 4 similar effects of plant density on Brix values were apparent but not statistically significant.

The mean Brix value for the lower internode at Period 3 was greater for Wf9 x C103 (7.25%) than for B73 x N28 (5.97%). In general, Wf9 x C103 tended to have larger Brix values than the B73 x N28 for both types of internodes and at all periods.

The fertile and sterile cytoplasms of both hybrids at various plant densities and periods of sampling had very similar Brix values.

Table 30. Mean Brix reading of upper internode of two hybrids with two cytoplasms for four plant densities at three different periods (1979)[a]

Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 2				
B73 x N28	F	4.27a	4.54a	3.94a	4.12a	4.46
	S	4.39a	3.93b	3.93a	4.07a	4.08
	Mean	4.33	4.23	3.935	4.09	4.27a
Wf9 x C103	F	4.51a	4.34a	4.36a	4.04a	4.31
	S	4.63a	4.39a	4.29a	4.22a	4.38
	Mean	4.57	4.36	4.32	4.13	4.34a
Mean of Fs		4.39	4.44	4.15	4.08	4.38a
Mean of Ss		4.51	4.16	4.11	4.14	4.23a
Overall mean		4.45a	4.30ab	4.13ab	4.11b	
		Period 3				
B73 x N28	F	6.88a	6.73a	6.11a	6.08a	6.45
	S	7.12a	6.36a	6.00a	5.72a	6.30
	Mean	7.00	6.54	6.05	5.90	6.37a
Wf9 x C103	F	8.04a	7.74a	6.67a	6.51a	7.24
	S	8.29	7.33a	6.50	6.77a	7.22
	Mean	8.16	7.53	6.58	6.64	7.23a
Mean of Fs		7.46	7.25	6.39	6.29	6.84a
Mean of Ss		7.70	6.84	6.25	6.24	6.76a
Overall mean		7.58a	7.04ab	6.32bc	6.27c	
		Period 4				
B73 x N28	F	9.10a	8.88a	8.68a	8.18a	8.71
	S	8.73a	8.80a	8.25a	8.53a	8.58
	Mean	8.91	8.84	8.46	8.35	8.64a
Wf9 x C103	F	9.35a	8.92a	9.27a	8.48a	9.01
	S	10.00a	9.38a	8.70a	8.92a	9.25
	Mean	9.68	9.15	8.98	8.70	9.13a
Mean of Fs		9.23	8.90	8.97	8.33	8.86a
Mean of Ss		9.36	9.09	8.47	8.72	8.91a
Overall mean		9.29a	8.99a	8.72a	8.53a	

[a]Means followed by the same letters are not statistically significant (P = .05). Letters are applied to means for the main effect of hybrid, cytoplasm and density, and for cytoplasm within a density and hybrid.

Table 31. Mean Brix readings of lower internode of two hybrids with two cytoplasms for four plant densities at four different periods (1979)[a]

Hybrid	Cytoplasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 1				
B73 x N28	F	3.25a	3.28a	3.09a	3.20a	3.20
	S	3.27a	3.14a	3.13a	2.89a	3.11
	Mean	3.26	3.21	3.11	3.04	3.15a
Wf9 x C103	F	3.19a	3.06a	3.15a	2.90a	3.07
	S	3.43a	3.26a	3.60a	3.49a	3.44
	Mean	3.31	3.16	3.37	3.19	3.26a
Mean of Fs		3.22	3.17	3.12	3.05	3.14a
Mean of Ss		3.35	3.20	3.36	3.19	3.27a
Overall mean		3.28a	3.18a	3.24a	3.12a	
		Period 2				
B73 x N28	F	4.47a	4.92a	4.12a	4.32a	4.46
	S	4.54a	4.36a	3.89a	4.19a	4.24
	Mean	4.50	4.64	4.00	4.26	4.35a
Wf9 x C103	F	4.91b	5.00a	4.17a	4.40a	4.62
	S	5.83a	4.60a	4.38a	4.32a	4.78
	Mean	5.37	4.80	4.27	4.36	4.70a
Mean of Fs		4.69	4.96	4.14	4.36	4.54a
Mean of Ss		5.18	4.48	4.13	4.26	4.51a
Overall mean		4.94a	4.72ab	4.14c	4.31bc	
		Period 3				
B73 x N28	F	6.26a	6.03a	5.95a	5.64a	5.97
	S	6.16a	6.26a	5.67a	5.81a	5.97
	Mean	6.21	6.14	5.81	5.72	5.79b
Wf9 x C103	F	7.94a	7.40a	6.98a	6.89a	7.30
	S	8.03a	7.34a	6.60a	6.84a	7.20
	Mean	7.98	7.37	6.79	6.86	7.25a
Mean of Fs		7.10	6.71	6.46	6.26	6.63a
Mean of Ss		7.09	6.80	6.13	6.32	6.58a
Overall mean		7.10a	6.76ab	6.30b	6.29b	

[a]Means followed by the same letters are not statistically different (P = .05). Letters are applied to means for the main effect of hybrid, cytoplasm and density, and for cytoplasm within a density and hybrid.

Table 31. (Continued)

Hybrid	Cyto-plasm	Plant density (plants/ha) 39,536	59,304	79,072	98,840	Mean
		Period 4				
B73 x N28	F	8.98a	8.63a	9.08a	9.18a	8.97
	S	9.28a	9.50a	8.43a	9.10a	9.08
	Mean	9.13	9.06	8.76	9.14	9.02a
Wf9 x C103	F	9.17b	9.05a	9.10a	8.80a	9.03
	S	10.47a	9.22a	9.00a	9.22a	9.48
	Mean	9.82	9.13	9.05	9.01	9.26a
Mean of Fs		9.07	8.84	9.09	9.00	9.00a
Mean of Ss		9.87	9.36	8.71	9.16	9.27a
Overall mean		9.47a	9.10a	8.90a	9.08a	

DISCUSSION

After the setback in the use of Tms due to the blight disease, Cms and Sms were developed as substitutes in hybrid corn seed production (Beckett, 1971; Smith et al., 1971; Gracen and Grogan, 1974). Besides tolerance or resistance to blight disease (H. maydis), other information needed on these newer cytoplasmic male sterile materials included yield characteristics. The results of the studies carried out in 1978 and 1979 have revealed that Cms and Sms produced effects on grain yields and plant characteristics comparable to those of Tms.

Plant density has been known to affect the grain yield of corn. Studies by Colville et al. (1964), Hunter et al. (1970), and Moll and Kamprath (1977) have shown that increases in plant density increase grain yield. Nevertheless, a point is reached in the increase where a yield decline is obtained as a result of increased barrenness. Colville et al. (1964) believed such a point to be 59,304 plants/ha in humid areas.

Yields obtained from my 1978 studies showed increases in grain yields across hybrids up to a density of 74,130 plants/ha. This increase occurred in each of the hybrids used for the experiment. Yield increased from 51.99 q/ha at 34,594 to 63.3 q/ha at 74,130 plants/ha. In 1979, a grain yield decline was observed when plant density was increased from

59,304 to 79,072 plants/ha. Yields across hybrids increased from 91.9 q/ha at 39,536 plants/ha to 97.8 q/ha at 59,304 plants/ha but dropped to 92.7 q/ha at density of 79,072 plants/ha.

There were significant yield differences among hybrids in both years of the experiment and this agrees with the results of previous studies. These studies have shown that maximum grain yields of hybrids may vary because of their differences in tolerance to high plant density and environmental factors (Schwanke, 1965; Lutz et al., 1971), prolificacy (Bauman, 1959; Collins et al., 1965), and maturity periods (Lutz et al., 1971).

Hybrids responded to plant density increases differently in the experiments and hence there were significant hybrid by density interactions for grain yields. Plant density effects on all hybrids in 1978 were positive; that is, there were yield increases at all plant densities for all hybrids. In 1979, when the range of density studied was from 39,536 to 98,840 plants/ha, hybrids showed some negative responses to plant density increases beyond 59,304 plants/ha.

Of greater importance in these studies was the effect of sterile and fertile cytoplasms on grain yields at the varying densities. In 1978, the mean grain yield of Cms and Sms cytoplasms of the hybrids used was greater than the mean of their fertile counterparts by 5.7 q/ha. The differences between the sterile and fertile in each hybrid at each level

of density were obvious and were significant in many cases, particularly at the higher densities. At the 54,362 and 74,130 plants/ha densities, the differences between sterile and fertile cytoplasm for Mo17 x B73 were 15.6 and 18.5 q/ha, respectively; for Wf9 x B37 the differences were 6.03 and 4.71 q/ha; and 1.70 and 8.86 q/ha for B37 x B73. The fertile and sterile cytoplasms of A554 x W182 were not significantly different in yield at any plant density. It was a short-structured and early maturing hybrid which may not have developed sufficient leaf area and plant size at the highest density to be under much of a plant density stress.

In 1979, the mean grain yield of sterile cytoplasm was greater than the mean grain yield of fertile cytoplasm by 17.2 q/ha. The sterile yielded greater than the fertile at both low and high densities in all hybrids except B73 x N28. I used B73 x N28 because it was thought to be one of the more plant density tolerant of the recently developed single crosses. The lack of a cytoplasm by density response in this hybrid indicates that it is very tolerant to plant density.

Yield advantages of the sterile over the fertile cytoplasm at the two highest densities were 18.6 and 37.3 q/ha for Wf9 x C103, 10.6 and 15.0 q/ha for Wf9 x B37, and 12.5 and 9.8 q/ha for B37 x B73. These results I obtained with C and S types of cytoplasms are in agreement with previous findings of Duvick (1958), Chinwuba et al. (1961), and Schwanke (1965) for Tms.

A comparison of three cytoplasms, normal, Cms and Tms, in the hybrid Wf9 x C103 in 1979, showed markedly less grain yield of the normal fertile cytoplasm compared to either of the two sterile cytoplasms. Mean yield differences across densities were 20.4 q/ha between normal and Cms and 23 q/ha between normal and Tms. At the 79,072 plants/ha density, the differences were 23.6 q/ha for normal and Cms and 26.3 q/ha for normal and Tms. At 98,840 plants/ha density, the Cms had 37.3 q/ha yield greater than the normal, and the Tms had 33.8 q/ha greater yield than the normal cytoplasm. The yields of Cms and Tms did not vary significantly. The yield of Tms was 101.1 q/ha at 79,072 plants/ha compared to 98.4 q/ha for Cms, but at the density of 98,840 plants/ha, Cms had a yield of 88.9 q/ha compared to 85.4 q/ha for Tms. These results support the apparent similarity in effect of Tms and Cms on grain yields.

Cummins and McCullough (1971) found no difference between silage yields of fertile and sterile cytoplasms. The results for dry silage yields in 1978 agree with that finding. The yields of silage of the fertile cytoplasm of all hybrids across densities and within hybrids at each density, were comparable to the yields of their sterile counterparts. This result may suggest that what barren plants fail to store in grain as a result of barrenness at high density they store somewhere else in the plant.

Silage yields, however, varied with hybrid and density.

Wf9 x B37 with 14.2 T/ha had the greatest silage yield although this was not significantly greater than 13.5 T for B37 x B73 and 13.1 T for Mo17 x B73. The yields of the three hybrids, however, were greater than the 10.6 T/ha for A554 x W182, an early hybrid. These results also tend to show that the greater grain yielding hybrid may not necessarily be the higher silage yielder. Mo17 x B73 was the highest grain yielder.

The densities of 54,360 and 74,130 plants/ha had more silage yield than 34,594 plants/ha by 2.3 and 3.6 T/ha, respectively.

Other plant characteristics measured during the studies included days to 75% silking, barrenness and stand count at harvest.

The several works cited in the Literature Review, including those of Duvick (1958), Schwanke (1965), and Bruce et al. (1966), have shown the reduction of barrenness under high plant density as an important attribute of Tms. In the 1978 results of my studies, plant density significantly affected barrenness; percentage of barren plants was greater at 74,130 plants/ha than at 34,594 plants/ha. However, neither hybrid, cytoplasm nor their interactions with density affected barrenness. The lack of cytoplasm and hybrid responses in 1978 may be attributed to the inadequately high plant densities that were used. In the 1979 experiment, the results obtained showed large responses to hybrid, density, cytoplasm,

and their interactions, with respect to percentage barrenness. The population tolerant hybrid B73 x N28 had the least response and probably was a major cause of the hybrid by density and hybrid by cytoplasm interactions.

At the density of 79,072 plants/ha and above, significant differences were found in the percentage barrenness occurring between fertile and sterile cytoplasms. Sterile cytoplasm reduced barrenness by 8 and 16.8%, respectively, in the population intolerant hybrids Wf9 x B37 and Wf9 x C103 at 79,072 plants/ha density, and by 11.5 and 38.2% at 98,840 plants/ha.

A number of workers, Sass and Loeffel (1959), Woolley et al. (1962), Schwanke (1965), and Cardwell (1967), linked delayed silking to the occurrence of barrenness under high plant density. Other studies have shown that time of silking under the high density planting is influenced by hybrid and male sterility. Values from studies by Jones and Mangelsdorf (1951), Marquez-Sanchez (1964), Schwanke (1965), and Vincent (1968), using Tms, have shown earlier silking ranging from 0.2 to 3.2 days for male sterile compared to the fertile plants.

In both years of my studies, increased plant densities delayed silking by about 2 and 3 days at the high compared to the low densities for 1978 and 1979, respectively, as other studies have shown.

Across hybrids, the male sterile reached 75% silking

significantly earlier than the fertile by 0.43 days in 1978. However, in 1979, the male sterile cytoplasm did not show any significant difference in date of 75% silking compared to the fertile cytoplasm, but there was a significant cytoplasm by density interaction which indicated that the effect of the sterile cytoplasm was more beneficial at high than low plant densities.

The results obtained for plant stand count at harvest in both years of the experiment showed that significant differences existed between the different densities used, as was designed and expected. Hybrids also showed differences, a result which confirms differences in tolerance to environmental stresses (Lutz et al., 1971). Of importance was the apparent lack of difference in stand count between fertile and sterile cytoplasms. This result confirms the fact that any differences in yield between the two cytoplasms was not related to stand differences between cytoplasms.

Results discussed so far concerning the hybrids used show that the effects of plant density and the effect of male sterile cytoplasm appear consistent with results of past studies on Tms.

An area that has continued to need clarification is why the sterile cytoplasm yields better than the fertile under increased plant density stress. To try to answer this question, measurements of the growth of different plant parts were made at certain periods in 1979, and the results of these

measurements were related to the development of the first ear.

Data obtained from these measurements basically show that the developing ear was faced with competition from other developing parts at some of the stages of growth. There was competition from the tassel and competition from the growing lower and upper internodes. The greater tolerance to high stand density of the sterile cytoplasm appears to be associated with the concept that other plant parts of sterile plants compete less with the ear as has earlier been proposed by some workers (Sanford et al., 1964, 1965; Grogan and Sarvella, 1964; Bruce et al., 1966; and Cardwell, 1967).

At the highest plant density, 98,840 plants/ha, the ear dry weight of plants with fertile cytoplasm was found to be less than that of sterile cytoplasm after Period 2, particularly with the high density intolerant hybrid Wf9 x C103. Although not statistically compared, Wf9 x C103 had a greater rate of ear growth between Periods 3 and 4 at the low density than did B73 x N28. This may in some way be a reflection of the strong one-earedness characteristic of this hybrid. With B73 x N28, the more tolerant hybrid, cytoplasm had little effect on ear weight compared to Wf9 x C103.

By the time the measurements were made at Period 3, the disproportionate effect of plant density on ear dry weight was evident for the fertile counterpart of Wf9 x C103. At the lowest density, the ear weight was 27.6 g and thus a weight

of 11 g was expected at the greatest plant density. The value obtained was 4.26 g or approximately 40% of the expected weight. For the male sterile counterpart, 90% of the expected weight was obtained. For B73 x N28 the values were 105% for the fertiles and 118% for the steriles. From these comparisons it is apparent that the causes of intolerance to high plant density acted and had a major effect on ear growth before the date silking was expected to occur. Therefore, growth of plant parts which could affect ear weight should have been evident in measurements at Periods 1 and 2.

The consistently greater tassel weight of fertile cytoplasm compared to the sterile cytoplasm at Periods 1, 2, and 3 signaled greater competition of the tassel with ear development in the fertile than in the sterile cytoplasm. Sanford et al. (1964, 1965) had found a considerably greater nitrogen level in fertile tassels than in sterile ones before pollen shed, and had concluded that competition between tassel and ear was for nitrogen. The greater tassel size might also result in greater shading and reduction of radiant flux to leaves among fertile plants than sterile plants as suggested by Duncan et al. (1967) and Hunter et al. (1969).

The more density intolerant Wf9 x C103 had a two- to threefold greater tassel dry weight than B73 x N28, which is a sign of greater competition with the ear in that hybrid compared to B73 x N28. Anderson (1971), using 23 lines of

corn, reported that delay in silking at high stand density was related to tassel size.

During Periods 1 and 2, tassel dry weights of the plants with fertile cytoplasm decreased proportionately less than expected with an increase in stand whereas the steriles decreased as much as expected based on values in Table 25. The tassel dry weight data show a greater demand for growth materials by tassels of fertile plants than by those of sterile plants during Periods 1 and 2.

Internode weight measurements made in 1979 showed significant cytoplasm by density interaction at Period 2 for internode lengths and dry weights. The upper and lower internodes of sterile plants grew less in length and weight than did those of the fertile as plant density was increased. This again means that at this period the internodes of the fertile with their greater growth activity posed a greater competition to the developing ear than did the lesser growing internodes of the sterile plant.

This finding may relate to the results of Grogan and Sarvella (1964 and Sarvella and Grogan (1965) who suggested that the reduced length of the above and below ear node internodes in sterile cytoplasm plants is the cause of the reduced ear height in these plants compared to their fertile counterparts. The length of both types of internodes at Periods 3 and 4 are also similar to the effects of plant density on mature plant height given by Meyer (1970).

Brix reading was used for an estimate of the relative stem sugar content (with sucrose in mind) rather than absolute sucrose contents. Cardwell (1967) had observed that male sterile genotypes had higher stem sugar content compared to the fertile genotypes, and he associated high sugar content with promotion of ear development. Brix values from my study showed that the fertile and sterile cytoplasm of both hybrids at various densities and periods of sampling were very similar. Nevertheless, it appeared that internodes needed a certain level of sugar in the stem for the internodes to elongate. Increased density reduced stem sugar as indicated by Brix readings.

During Periods 1 and 2, tassel and internodes of sterile plants grew less than did these parts of the fertile plants. The effect appeared to be greater for the intolerant hybrid than for the tolerant hybrid. I propose that the reduced growth of these plant parts, and of other tissues similar to them, is the reason the ear of the sterile plant is better able to grow and produce viable silks near the time anthesis would be expected. One causal mechanism could be that the fertile tassel produces greater amount of growth hormones promoting stalk enlargement and obligating sugar accumulation than does the sterile tassel. Another explanation is that the fertile tassel merely acts as a competitor of the ear for growth materials.

SUMMARY AND CONCLUSIONS

Experiments were conducted during the summers of 1978 and 1979 to assess the grain and silage yields of hybrids containing the C and S male sterile types of cytoplasm, and to determine the relationships between growth of some plant parts and ear development in these hybrids.

The experiments were conducted in fields close to the city of Ames, Iowa using a split-split plot design during the two years.

In the first year of the experiment, four male sterile hybrids: Wf9CmsHt x B37Ht, B37CmsHt x B73Htht, A554MysHtht x W182BN and Mo17WmsHtht x B73, and their fertile counterparts were studied under three plant densities, 34,594, 54,362, and 74,130 plants/ha. During the second year, another four hybrids including a Tms component: Wf9CmsHt x B37Ht, B37CmsHt x B73Htht, B73CmsHt x N28Ht, and a Wf9 x C103 separately carrying Cms and Tms cytoplasms, and their fertile versions were tested under four plant densities, 39,526, 59,304, 79,072, and 98,840 plants/ha.

Measurements of growth of plant parts were made at different periods between 23 July and 17 August 1979, for the two hybrids, Wf9 x C103 and B73 x N28, each with fertile and Cms cytoplasms, and these represented high plant density intolerant and tolerant varieties, respectively. Parts and measurements taken included tassel weight and length, ear

weight and lengths, internode lengths and weight and stem sugar content (by Brix reading). Other observations which were made for all hybrids included: days to 75% silking, percent barrenness, stand count at harvest, and finally, grain yields were taken.

Data collected were interpreted on the basis of statistical analysis of variance and knowledge of physiological processes of the corn plant.

The major aspects of the results obtained are as follows:

In both years of the experiment, yields across hybrids varied significantly with plant density. In 1979, yield reductions of 4.6 and 13.81 q/ha were obtained for the two plant densities greater than 59,304 plants/ha. Hybrids also varied in yields across density. Mo17 x B73 with 65.8 q/ha was the greatest yielder in 1978, while A554 x W182 was the least yielder with 55.6 q/ha. In 1979, B73 x N28 with 95.8 q/ha gave the greatest grain yield. Wf9 x C103 gave the least yield with 87.9 q/ha.

In both years of the experiment the mean yield of the sterile cytoplasm was greater than that of the fertile cytoplasm, by 5.7 q/ha in 1978 and 17.2 q/ha in 1979.

Silage yield which was taken only in 1978 varied with hybrid and density but not with cytoplasm.

Other plant characters that were significantly affected by density and cytoplasm were barrenness and days to 75% silking. Increased density resulted in increased barrenness

by as much as 3.77% from a density of 34,594 to 74,130 plants/ha across hybrids in 1978, and similarly by 22.4% from a density of 39,536 to a density of 98,840 plants/ha in 1979. Hybrids varied in their degree of barrenness. Across hybrids and densities the fertile cytoplasm had 4.4% more barren plants than the sterile cytoplasm in 1979. The density used in 1978 did not create enough stress to show a difference in cytoplasm.

Increased density delayed silking by about 2 to 3 days at the high plant density in comparison to low density, and so did fertile cytoplasm compared to the sterile.

Significant differences were maintained in stand count at harvest for the different plant densities during both years of the experiment. Plant stand count at harvest varied also for hybrids, but stand counts for sterile and fertile cytoplasm were similar.

Data on the growth of plant parts showed that ear dry weight declined with increased plant density in the two hybrids studied. Ear weight decline was greater for the fertile at the highest density after Period 2 than for the sterile cytoplasm.

Increased plant density reduced size of tassel for both fertile and sterile cytoplasms in the two hybrids. However, tassels of plants with fertile cytoplasm were larger, grew more during Periods 1 and 2 and declined proportionately less with increased density than did the sterile counterpart.

Although the interaction of density and cytoplasm was not significant for the lower internode, both the upper and lower internodes grew more in the fertile cytoplasm between Periods 1 and 3 as plant density increased than did those of the sterile cytoplasm.

Brix reading varied with density in Periods 1 to 3. The two hybrids also varied in Brix value with Wf9 x C103 tending to have higher values. Brix values did not vary with cytoplasm.

In general, growth of tassel and internodes was greater for the Wf9 x C103 than for B73 x N28.

The objectives of the studies again basically are: to assess (by grain and silage yields) the performance of some hybrids carrying the C and S male sterile cytoplasm, and to explain the often greater yields of male sterile compared to male fertile corn in high plant densities by considering relationships of growth of plant parts. The following conclusions can be drawn from the results obtained.

Since the grain and silage yield responses of the hybrids to density and cytoplasm were similar to results obtained for Tms in the past, and since the effects on barrenness and silking were found to be similar also and, since the grain yield of Cms did not differ from that of Tms, the Cms and Sms cytoplasms can be said to be as good as Tms in use for corn production.

In relating the growth of the tassel and internode to the growth of the ear, it was found that the sterile plants showed less competition to the ear by these plant parts under condition of plant density stresses during the early and crucial stages of ear development.

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